Utah Agricultural Water Optimization -
Water Savings from Drip Irrigation

Report

L. Niel Allen, Alfonso Torres-Rua, Anastasia Thayer Hassett, Ryan Larsen, Matt Yost
Utah State University

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Executive Summary

Utah House Bill 381, Agricultural Water Optimization includes directives and funds for assessing applicable agriculture irrigation water conservation technology (Utah Legislature, 2018). A study in 2019 and 2020 evaluated differences in consumptive water use or depletion between drip and surface irrigation onions. Drip irrigation is a good irrigation water optimization technology and can reduce diversion by over 50 percent (25 v. 50 or more inches) and reduce consumptive use by about 20 percent (from about 25 v. 30 inches per year). Findings show that adequate soil moisture and onion stands of between 110,000 (5.8-inch spacing between onions) and 180,000 (3.6-inch spacing) plants per acre are important. However, only one drip irrigated field had uniform and adequate soil moisture throughout the season to produce the high yields that occurred in the two best surface irrigated fields. The other drip irrigated fields had lower soil moisture levels during the season resulting in lower and non-uniform yields. With good design and proper management, drip irrigation can result in high yields while conserving water. Providing tools and information on drip irrigation design and scheduling (when and how much to irrigate) are needed to optimize yields and returns on investments. Crop coefficients were developed that can be used for irrigation scheduling and estimating irrigation water use.

Based on the fields evaluated, drip irrigation has the following benefits.

- Requires less than half of the diversion of surface irrigated onions. This is critical when water supplies are limited.
- Reduces depletion about 0.25 to 0.4 acre-feet per acre for equivalent yields within the cropped area of the field with most of the reduced depletion occurring in May and June.
- The equipment turning areas (about a 15-foot strip) at the ends of the field are not irrigated. This reduces the irrigated area by 3 to 5 percent, saving water lost to evaporation from wet soils. This is an additional reduction in depletion.
- Provides the capability to establish onions with uniform germination and good stands. The highest yielding fields were established with drip irrigation, even though the drip system was not used after establishment.
- Provides excellent irrigation and fertilization management capabilities.
- Reduces irrigation labor requirements during the irrigation season.
- Irrigation requirements for a well-designed and managed drip system are about 26 inches during the May through August period. The irrigation requirement can vary due to precipitation and temperatures.
- Based on the fields evaluated, the onion yield per unit of water applied is about twice that of surface irrigation.

There are disadvantages of drip irrigation, including.

- Drip can be used to apply small amounts of water and under irrigation and/or irrigation non-uniformity can easily occur resulting in field areas with low yields. Under-irrigation can be prevented by proper irrigation scheduling.
- The cost of the drip system and the energy requirements. These costs can be offset as suggested by the use of drip to establish onions even when surface irrigation is used.
- Require time for installation, setup, and removal.

Limitations to the implementation of drip irrigation, include.

- Water availability from a timing perspective can prevent proper irrigation scheduling and limit irrigation time. Most irrigation water-turn rotation schedules limit the use of drip irrigation systems that are dependent on having water more frequently and for longer periods than provided by the water rotation schedule.
- The cost and land required to build an on-farm water storage reservoir so that irrigations can occur on-demand as drip irrigations are needed.

From an economic analysis not considering water supply, yields under the furrow irrigation system in the studied area and period were higher than yields under drip irrigation. However, the high-yielding fields used drip irrigation to establish the onion crop. The slightly lower costs of furrow irrigation resulted in higher estimated yearly returns and net present value for onions grown under furrow irrigation compared to drip irrigation. However, it is important to note that the observed yields under furrow irrigation, were higher than past studies and data reported by USDA (yields under drip irrigation were also higher than usual, although not as high) and two of the drip irrigated fields were under irrigated. Thus, the yearly returns and NPV under furrow irrigation might be overestimated in this study because drip irrigation was used for establishment. This study illustrates that onion production under drip irrigation may not be as profitable as production using furrow irrigation unless yields under drip irrigation are higher, and onion growers in Utah may need other incentives to consider the switch to a more water-efficient drip irrigation system. However, based on the irrigation and soil water information, under irrigation occurred on the drip fields which can be corrected.

Recommendations

The research shows that drip irrigation reduces irrigation diversions, consumptive use, fertilizer use, and labor. However, with adequate irrigation water availability, surface irrigation costs slightly less, and good yields can be produced. However, drip irrigation is better for establishing the onions. The following items would encourage the use of drip irrigation.

- A major impairment to increasing drip irrigation season-long use and improving irrigation efficiency is the water supply delivery capabilities of the canal systems. Piping canals and laterals are expensive, but the downstream water control at the turnouts makes it much easier to provide water to users on demand. Likewise, automated ditch systems are expensive but can help an open canal system deliver water more efficiently and provide more flexibility in delivery quantities and timing.
- A cost-share program to provide funding to help encourage the use of drip irrigation resulting to reduced consumptive use and diversions and provide a benefit to the state. A system would also need to be in place so that decreased diversions and reduced CU is available for alternative water uses that benefit the funders.
- Provide education on the best management practices, soil moisture monitoring, and irrigation scheduling for drip irrigation systems so that good yields are obtained. This education can be from grower-to-grower, consultants, and industry experts, or Extension educators.
- Provide irrigation water delivery flexibility so that producers can use their water shares in different locations to increase total production.

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Introduction

Agriculture water optimization is important in Utah due to increased water needs, limited water supply, drought, and climate changes which affect water supplies and water use. Water shortages can dramatically affect agricultural, municipal, and environmental users. Agriculture diverts about 80 percent of all diversion in Utah. Utah House Bill 381, Agricultural Water Optimization includes directives and funds for assessing applicable agriculture irrigation water conservation technology (Utah Legislature, 2018). An Agriculture Water Optimization study began in 2019 to determine differences in consumptive water use or depletion between drip and surface irrigation onions. Onions were selected because Utah growers currently use both drip and surface irrigation.

Agriculture water optimization in Utah is more complicated than irrigation efficiencies and irrigation diversions. Much of the state is within closed basins where water flows to terminus water bodies or playas. For example, the Great Salt Lake which supports significant industries requires adequate water to protect environmental resources and air quality. In many areas of Utah, irrigation diversions provide water for crop production and return flows or groundwater recharge for other water users. Without proper consideration improving irrigation efficiency can increase consumptive use and impair the water rights of others or be harmful to the environment (Grafton, et al., 2018). For this reason, depletion from irrigation is emphasized.

Drip irrigation is a good candidate for agriculture water optimization because drip irrigation can maintain or improve crop production with proper management while consuming less water. Drip irrigation is used on commercial onions in Box Elder and Weber County, Utah. Studies have shown that properly managed, drip irrigation provides excellent water management capabilities, helps control weeds, can improve yields and onion size uniformity, reduces labor when compared to furrow irrigation, reduces fertilizer input, and significantly reduces irrigation diversions by eliminating tail-water runoff and minimizing deep percolation (Shock, et al., 2013, Enciso, et al., 2015, and Maughan, et al, 2015). Irrigation management is critical to onion yield and quality as onion production is sensitive to soil water availability. The acreage of drip-irrigated onions in Utah is expanding as growers seek to improve irrigation and fertilizer management and conserve water.

Estimates of ET and net irrigation requirements of onions in Box Elder County are published in a 2011 consumptive use report prepared by Utah Agriculture Experiment Station (Utah, 2011). However, these values are not based on field measurements in Utah. Table 1 summarizes the USU electronic weather station estimates are based on a Penman equation reference ET and crop coefficients and the National Weather Service are based on a calibrated NRCS Blaney-Criddle equation. The crop ET-based methods and averages are 28.97 and 31.85 inches, and the net irrigation requirements (depletion) are 23.97 and 28.83 inches (Utah DNR, 2011).

Table 1. Published estimated onion ET and net irrigation based on weather data, reference ET, and crop coefficients (Utah DNR, 2011).

	MAR	APR	MAY	JUN	JUL	AUG	SEP	**TOTAL**
Tremonton USU Electronic Weather Station (2003-2010)								
Crop ET (in.)	0.02	3.02	6.18	10.56	8.95	3.12		**31.85**
Net Irrigation (in.)		1.42	5.34	10.49	8.58	2.99		**28.83**
Tremonton National Weather Service Site (1971-2008)								
Crop ET (in.)		1.81	4.87	9.81	9.11	3.32	0.05	**28.97**
Net Irrigation (in.)		0.06	4.05	9.1	8.45	2.31		**23.97**

Transpiration of crops is closely related to the yield of crops, while decreased irrigation can reduce transpiration it can also reduce yields. Field-level water consumptive use also includes evaporation from the soil, open water, sprinkler spray, ET of weeds in fields, and other non-crop vegetation. Yield is a function of many processes and inputs, with transpiration by the crop being a major factor. Irrigation provides water for transpiration; however, irrigation water also evaporates from the soil and other surfaces and can leave the field by runoff and/or deep percolation.

Properly managed drip irrigation increases the fraction of the water applied used for crop transpiration and yield. For onions, the drip tape is generally placed a few inches under the soil surface and only wets a portion of the soil surface (Figure 1). The irrigation frequency of drip irrigation can be a couple of days to a week, while for surface irrigation it is not practical to irrigate as often and can be limited by irrigation turns (predetermined schedule). For onions, surface irrigation wets most of the ground surface as water seeps from the furrow to beds (Figure 1).


Figure 1. Sub-surface drip (left) and surface irrigated onions (right) in West Weber, Utah (2019).

Other components of the onion irrigation water budget include deep percolation and ET contribution from shallow groundwater. The deep percolation was estimated using data from the soil water sensors. In many locations, most of the water leaving the field as deep percolation or surface runoff returns to the surface or groundwater system and can be available for other uses. In some cases, a portion of the non-consumptive field losses can be lost to the atmosphere by increase consumptive use in drains and waterways or becomes part of water sources that are not available for other water users.

Objectives

The objectives of this study are to measure water use (depletion) of onions under surface and drip irrigation (determine the potential consumptive water use saving of drip irrigation of onions) and to provide yield data for economic analysis of drip and surface irrigated onions. To accomplish the objectives, data was collected included field irrigation inflow, field surface irrigation outflow, soil moisture, soil temperature, and yield at three locations in 3 drip irrigated fields and 3 surface irrigated fields.

Methodology

The water balance method of estimating ET was selected as most suitable for this research. A mass-energy balance of the soil was used to estimate the difference in soil evaporation between drip irrigated and surface irrigated onions to determine the potential consumptive water use saving of drip irrigation of onions.

Soil Water Budget

The simplest field-level water balance is ET from irrigation is equal to irrigation inflow minus irrigation outflow (runoff and deep percolation), minus increase in soil water storage. The inflow also includes precipitation and groundwater contributions, and the outflow includes deep percolation. The ET equation from the soil water budget is:

> ET = Irrigation + Precipitation + Groundwater contribution– Deep percolation ± change in soil moisture:

Units are measured in volume and then converted to depth by dividing by an area. This study uses depth in inches.

- Irrigation is measured by flow meters, rain gauges, and increase in soil water during irrigation.
- Precipitation is measured by rain gauges.
- Groundwater contributions are part of irrigation water or negligible due to the depth of the water table.
- Deep percolation is estimated by measured changes in soil moisture (e.g. decreases in soil moisture that are greater than available energy to transpire or evaporate water).
- Changes in soil water measured by soil moisture sensors.

The water balance components are shown in Figure 2.

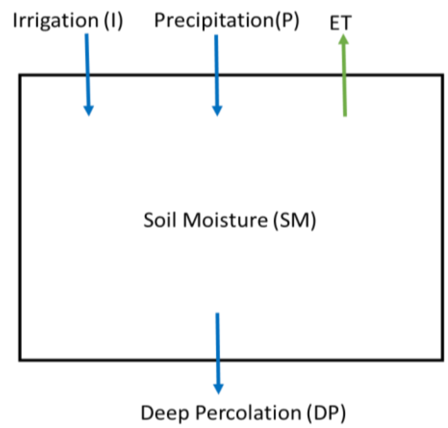


Figure 2. Simple soil water budget indicating major inputs, outputs, and soil water. No contribution from groundwater is assumed.

There are several considerations when using the soil water budget. First the measurements are point locations and there are differences in the field. However, using several locations provides a good estimate of ET, especially if the locations provide the same results. The basic equation is shown below. At a point measurement, the soil moisture is measured; the irrigation and deep percolation are not measured.

$$ET = SM_{beg} - SM_{end} + I + P - DP \text{ (as defined in Figure 2)}$$

ET can be directly estimated when there is no irrigation, precipitation, or deep percolation. This condition is common in an arid area like Utah. Deep percolation occurs when ET calculated from soil moisture is more than ET_{est}. For example, if ET calculated from SM is 0.75 in/day and estimated ET as estimated based on reference ET and crop coefficients is 0.25 in/day, then deep percolation occurred. Other considerations not included the soil moisture budget is evaporation from the soil surface and plant water use in the top inch or so of the soil. The soil moisture sites were equipped with near-infrared radiometers to measure soil/canopy temperature. This data can be used to estimate soil evaporation using an energy balance. Other data measured by sensors include soil temperature, soil water electrical conductivity, and soil matrix electrical conductivity. The temperature data is used for the energy balance and the salinity data is used for irrigation management. Another source of water for plant ET is contributions from groundwater.

Energy Balance to Estimate Soil Evaporation

The change in temperature of a defined mass results from a change in energy. Energy added to the mass increases the temperature of the mass and energy losses decrease the temperature of the mass. For a mass or volume of soil in the field, the primary energy inputs are radiation from the sun (shortwave) and radiation from the atmosphere (longwave). The primary energy losses from a soil mass are soil water evaporation (due to the latent heat of vaporization) and longwave radiation. The energy inputs and losses can be measured or estimated.

The soil data collected includes 10 temperature and soil moisture measurements (at the locations shown in Figure 4) taken every half-hour, along with the surface temperature measurement taken every 15 minutes for each measurement location. This data can be used to calculate the change in energy of the soil and convert it to radiation and evaporation. The total KJ/C° = sum of the mass (kg) times specific heat (kJ/kg/C°) for temperature and soil moisture measurement was compared between drip and surface irrigated fields.

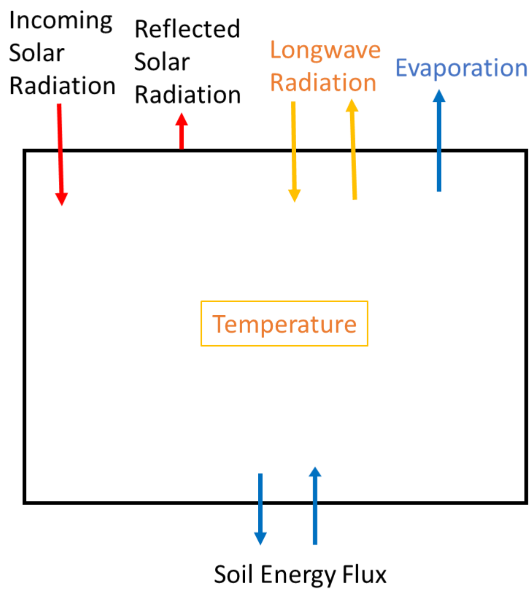


Figure 3. Energy balance components of a soil mass.

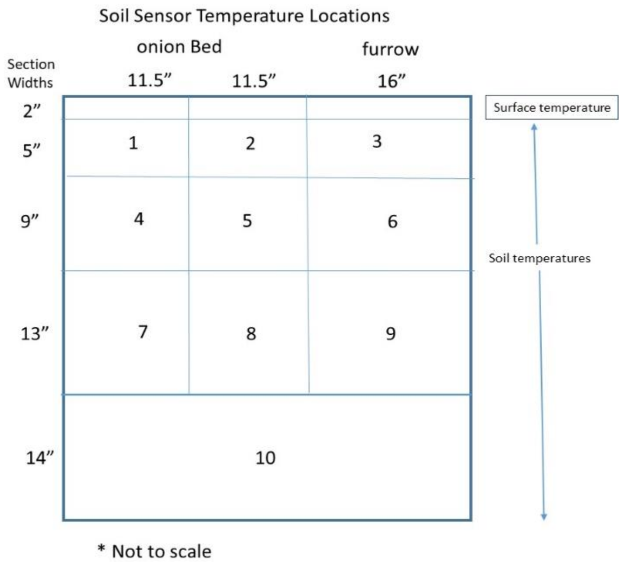


Figure 4. Soil temperature probe locations in the soil (numbers are probe identification).

The analysis is based on solar radiation and the soil heat flux at the bottom of the soil block is nearly the same for both surface and drip locations. The data shows nearly all the energy gained during the day is lost at night for both surface and drip irrigated fields and the minimum surface temperature is usually the same for both irrigation methods. The exception is during a surface irrigation event.

The energy per C° in a mass of soil is based on the specific heat capacity of the basic composition of the soil mass (soil mineral, water, and air). For soil, the significant components are the water content and the soil mineral. Table 2 is an example of the energy (KJ/C°) of 1 m^3 of soil (2211.5 KJ/C°). As an example, on a specific day if the surface irrigated soil mass is 2 C° cooler than the drip irrigated soil, then 4,423 KJ would need to be lost each day because minimum soil temperatures are approximately the same each night. The latent heat of water 2265 kJ/kg/C°, so the evaporation would be (4,423 KJ/2265 kJ/kg) 1.95 kg of water or a depth of 1.95 mm (0.078 inches) on the 1 m^2 surface area. This assumes the water content of both soil masses is the same.

Table 2. Example of specific energy per C° for 1 m3 of soil.

Surface irrigated	Percent by volume	Volume	specific gravity (gm/cm^3	Weight/ mass (kg)	Specific Heat (kJ/kg/C°)	Total KJ/C°
total volume (m^3)		1				
water	25%	0.25	1	250	4.184	1046.0
soil mineral	60%	0.6	2.65	1590	0.733	1165.5
air volume	15%	0.15	negligible			
Total	**100%**	**1**		**1840**		**2211.5**

Later in the season after the onions canopy matures the temperature difference is less due to less exposed wet furrows. The reason that the drip irrigated fields drop to about the same temperatures each night as the surface irrigated fields is because of radiation. The hotter surface temperature of the drip irrigated soils gives off more radiant energy than the cooler soils.

Crop Coefficients

Methods of estimating crop ET has been established using weather data to calculate a reference ET of a defined surface of well establish and healthy vegetation (e.g. grass or alfalfa) at a specific height range. There are numerous versions and methods to calculate a reference ET, this analysis uses the ASCE Standardized Penman-Monteith method with a grass reference (ETo). The method is based on available energy to evaporate water and uses temperature, humidity, solar radiation, and wind weather data to determine physical parameters that affect ET. A reference ET makes it possible to estimate crop ET using crop coefficients (Kc) that are specific to a crop and crop growth stage or development. The equation is, $ET_{crop} = Kc * ETo$. The United Nations Food and Agricultural (FAO) published Kc for onions range from 0.7 for initial growth, 1.05 for mid-season, and 0.75 for end of the season (Allen, et al., 1998).

Estimated crop ET allows for irrigation scheduling, which include the amount and timing of irrigations. In this study, Kc values were estimated on a daily time step based on the equation of $Kc = ET_{crop} / ETo$, where ET_{crop} is estimated based on the soil water budget and soil evaporation calculations.

Results and Discussion

Field Research Sites

Three drip irrigated and three surface irrigated onion fields were evaluated, in 2019 a surface and drip irrigated field in West Weber, Utah, and in 2020, a drip and surface irrigated field in West Weber and Bear River City, Utah. Figures 5-10 show the fields and the location of the sensors and flowmeters. All aerial photos were copied from Google Earth.

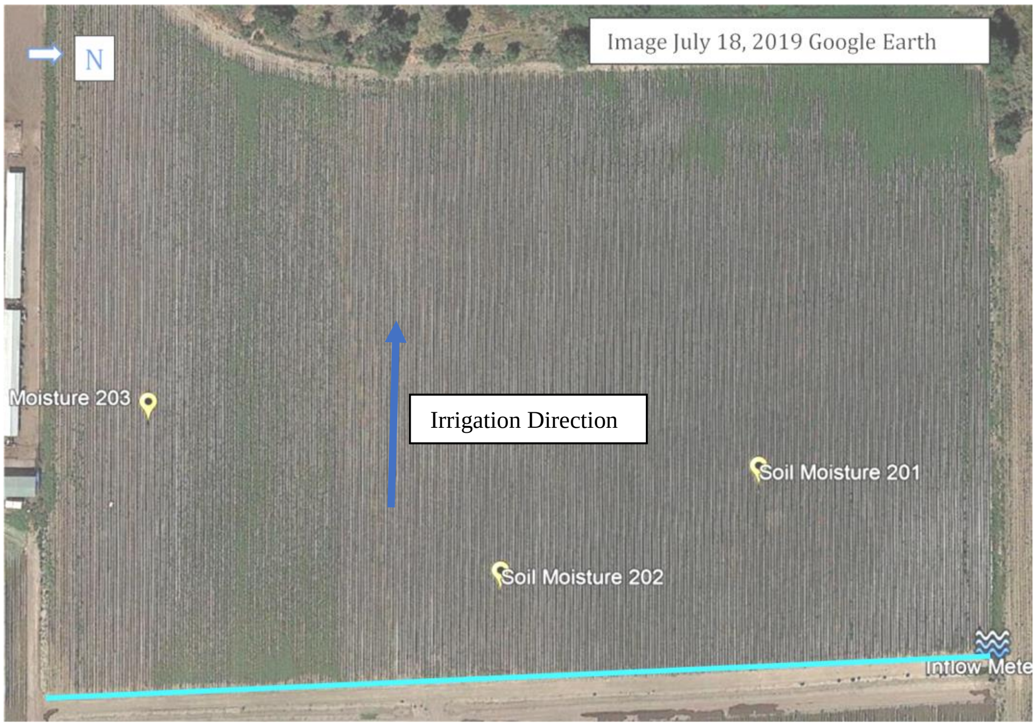


Figure 5. Field 1 2019 drip irrigated field. The drip PVC lay-flat manifold is indicated by the line at the bottom of the image.

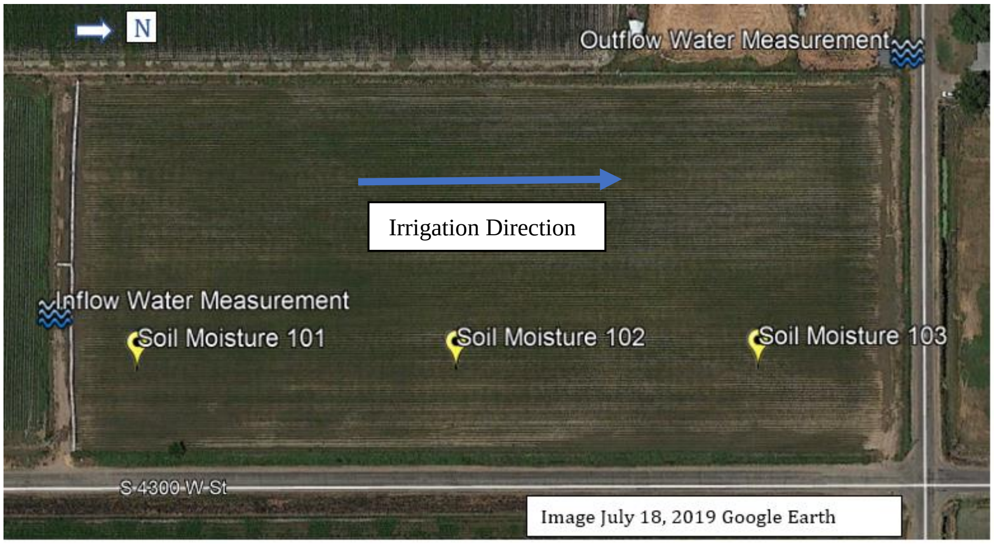


Figure 6. Field 2 2019 surface irrigated onion field. Lay flat PVC pipe can be seen on the left edge of the image.

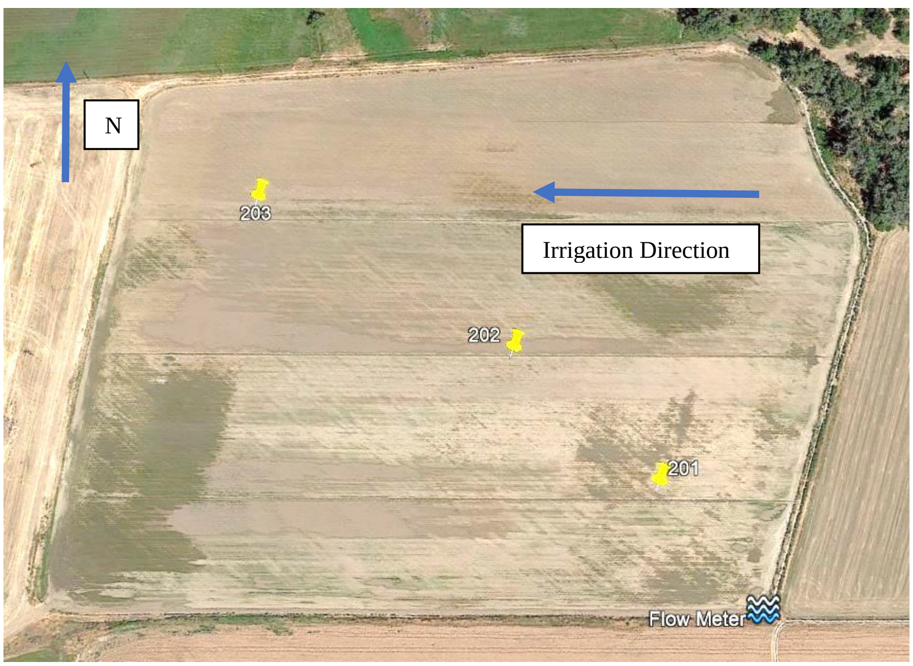


Figure 7. Field 3 2020 drip irrigated field (Google Earth photo taken July 18, 2019).

Figure 8. Field 4 2020 surface irrigated field (Google Earth photo taken July 18, 2019).

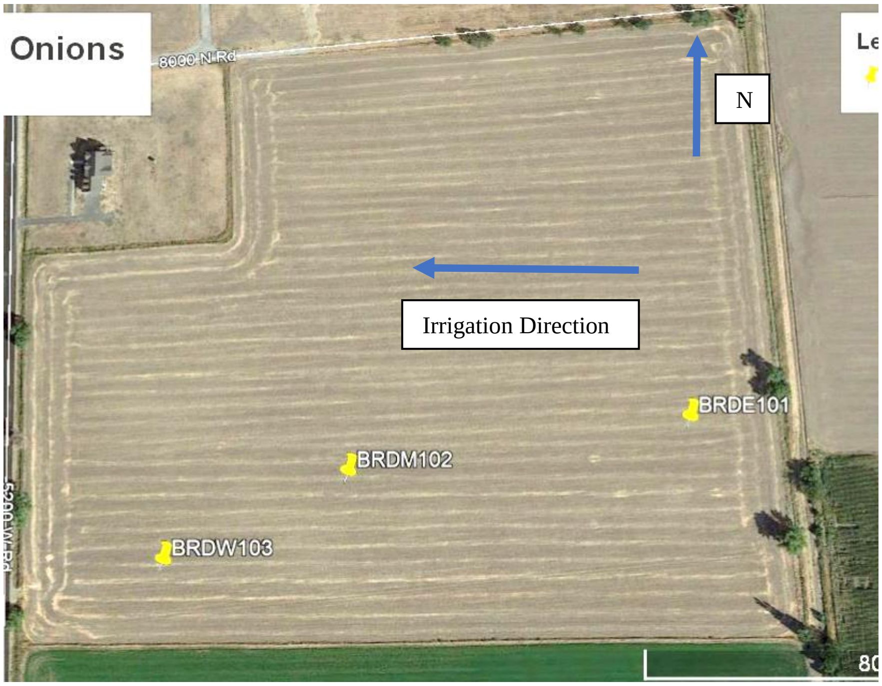


Figure 9. Field 5 2020 drip irrigated field (Google Earth photo taken September 14, 2018).

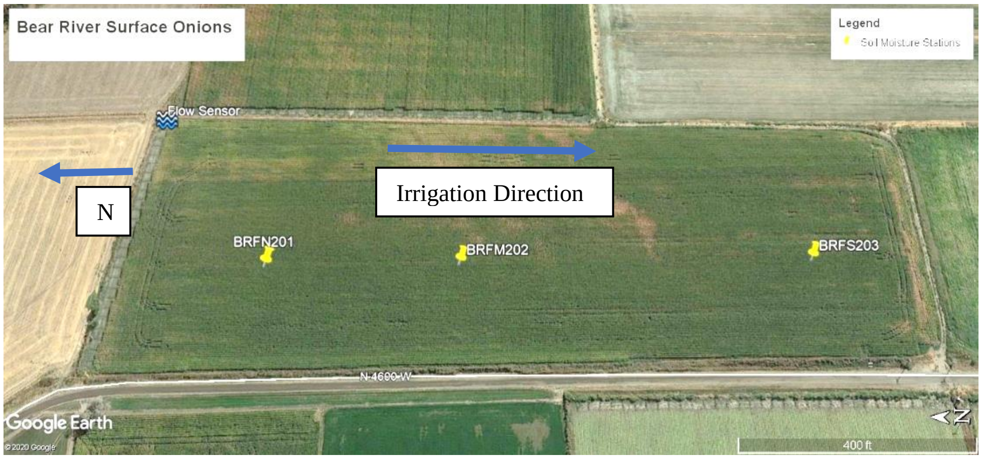


Figure 10. Field 6 2020 surface irrigated field (Google Earth photo taken September 14, 2018).

Table 3 contains a description of the year, onion variety, irrigation method(s), planting, and onion lifting dates for the 6 fields. The spring of 2019 had more rain than normal making timely planting difficult. Ideally, onions would be seeded in late March or early April, in 2019 many farmers were not able to plant until the end of April or early May. The surface irrigated onions were seeded on April 27, 2019, with Garnero onions and harvested on September 24, 2019. The surface irrigated onions were drip irrigated to germinate and establish the onions before the first surface irrigation in June. The drip irrigated onions were seeded at various times in the earlier part of April with Joaquin onions and harvested on August 23, 2019. For yield comparisons, ideally, the drip and surface irrigated onions would be the same variety and planted and harvested close to the same dates. The yield is also a function of irrigation, fertilization, planting density, pest management, harvest date, etc. However, the water use comparison which is a primary objective is valid. In 2020, all the fields were planted March 21-25, the fields were planted to Hamilton onions and the fields were all harvested at about the same time. This removed the variables of planting date, onion variety, and harvest dates.

Table 3. Description of fields evaluated in the study.

Field	Year	Variety	Establishment	Irrigation	Planting	First Irrigation	Onions Lifted
1	2019	Joaquin	No irrigation	Drip	April 5-15	May 6	Aug 24-25
2	2019	Garnero	Drip	Surface	April 27	June 9	Sep 24
3	2020	Hamilton	Drip	Drip	Mar 21-25	May 1	Sep 2
4	2020	Hamilton	Drip	Surface	Mar 21-25	April 12	Sep 3
5	2020	Hamilton	Drip	Drip	Mar 21-25	May 9	Sep 5
6	2020	Hamilton	Surface	Surface	Mar 21-25	April 21	Sep 4

Irrigation and Soil Water

Irrigation deliveries and runoff (surface fields) were measured at 6 fields and soil moisture was monitored are 3 locations in each of the fields. As an example, Figure 11 is the irrigation water deliveries to the 2020 drip and surface irrigated fields in West Weber. The drip irrigated fields had no surface runoff or water in the furrows during the irrigation period. The surface irrigated field had 5 drip irrigation events in April and May, and 12 flood irrigation events beginning in June. The surface irrigated field had 64.5 inches of irrigation, 22.6 inches of measured runoff, and approximately 14 inches of deep percolation, with the balance being plant transpiration and soil evaporation. The drip system had no runoff and an insignificant amount of deep percolation at one location on the field. Ideally, there should be some deep over about three-quarters of the field to avoid yield loss from crop stress.

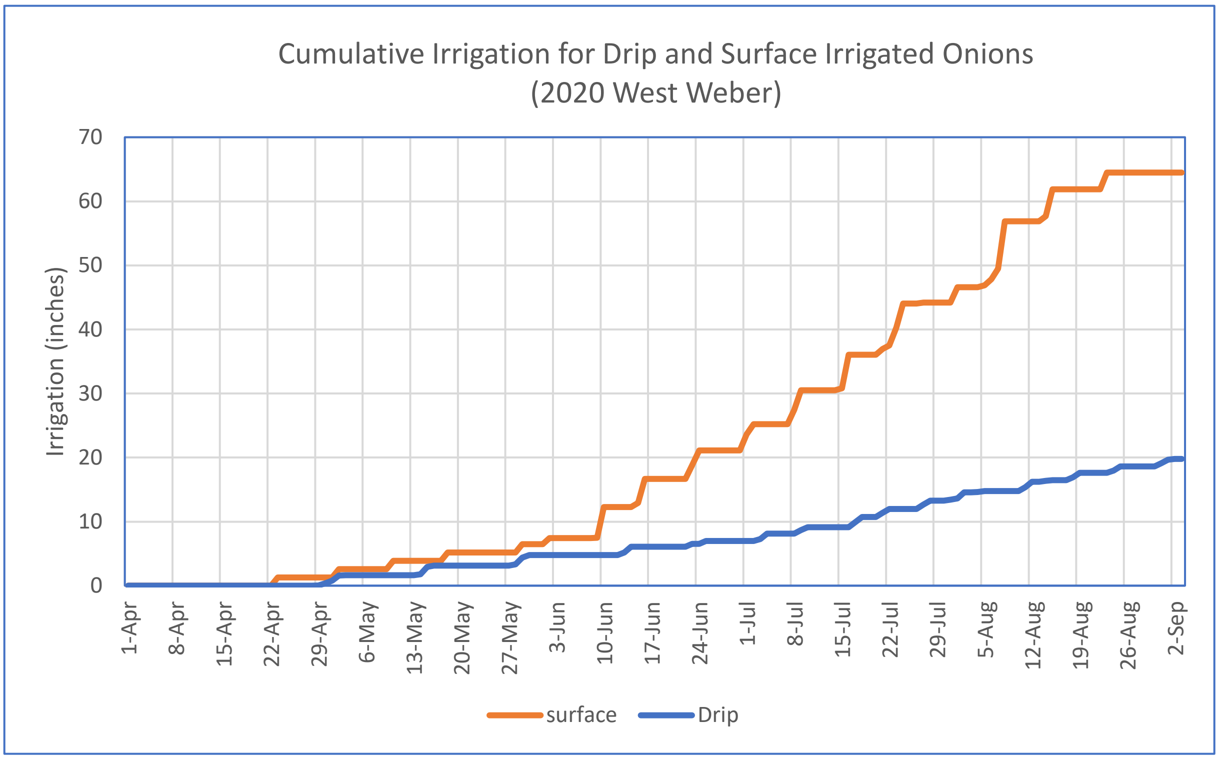


Figure 11. Cumulative irrigation deliveries to West Weber fields in 2020.

As described, the soil moisture was measured in 10 positions in the soil at 3 monitoring stations in each field. Figure 12 is an example of the soil moisture readings taken every half hour in Field 2 (surface irrigated) for 38 days. Each irrigation results in an increase in soil moisture followed by approximately one day of drainage. The time between the rapid drianage after irrigation and the following irrigation reflects soil moisture loss from crop ET. For this field, the shallower soil lost more water deep soil and the deeper soils, with the deepest soils staying near saturation. All the soil moisture data for 18 locations are used in the analysis but are not shown.

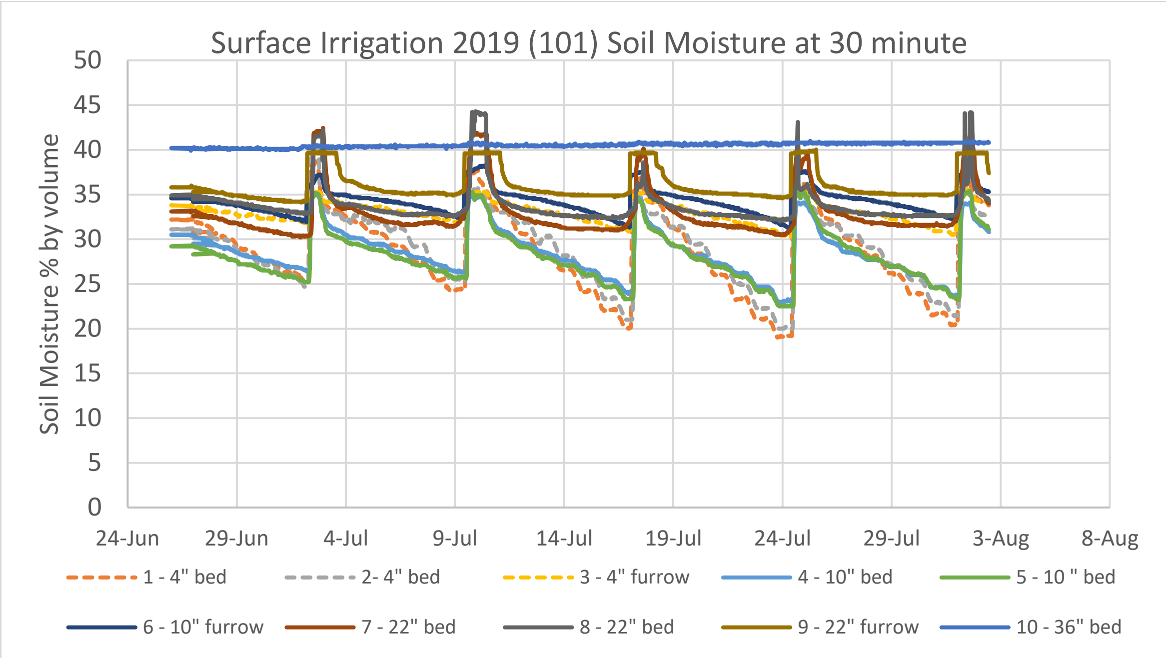


Figure 12. Soil moisture percentage for sensors at one location in Field 2 druing 2019.

Figure 13 shows the daily soil moisture totals (mid-night) readings for the two fields evaluated in 2019. Field 1 (drip irrigated) had two sites with similar soil moisture and the third site that was 1,350 feet from the drip manifold inlet had a much lower soil moisture. This difference in soil moisture is due to less water being applied at the site due to lower pressure in the drip line than at the other sites. The other Field 1 locations had about the same drip line pressure and irrigation application rate. Field 2 (surface irrigated) has higher soil moisture than the drip irrigated field and all locations were similar in the total water. Field 2 had much more water applied during the irrigation season. Figure 14 are the average of the three soil moisture sites for the four fields evaluated in 2020. The surface irrigated field maintained higher soil moisture than the drip irrigated fields. Field 5 which was drip irrigated maintained consistent soil moisture and also had high yields. The soil moisture in Field 3 had a decline during the season and a lower yield than the Field 5. Figure 15 is the daily total soil moisture for Bear River City fields irrigated in 2020 for each of the soil moisture stations. The drip irrigated field had a slight decline in soil moisture near the end of the season. Figure 16 is the average total soil water by fields for the fields evaluated in 2020. The soil water in the drip fields varied less between irrigations but was overall lower than the soil moisture in the surface irrigated fields.

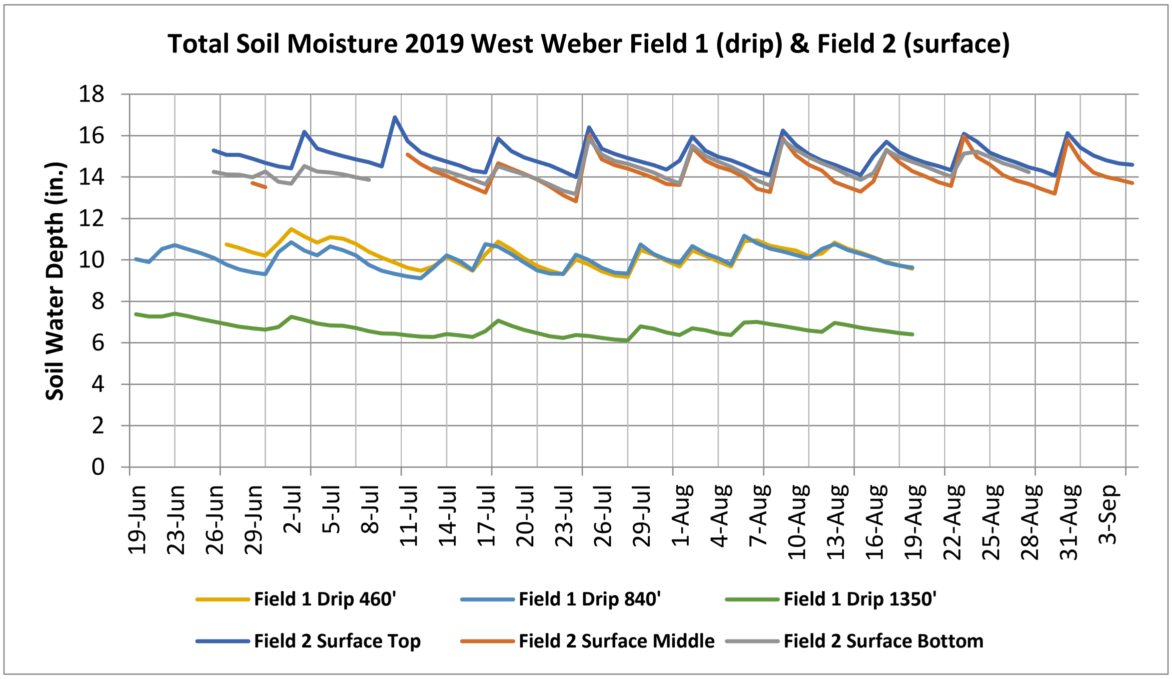


Figure 13. Daily total soil moisture for fields irrigation in 2019. The legend indicates the distance or position for the field inlet.

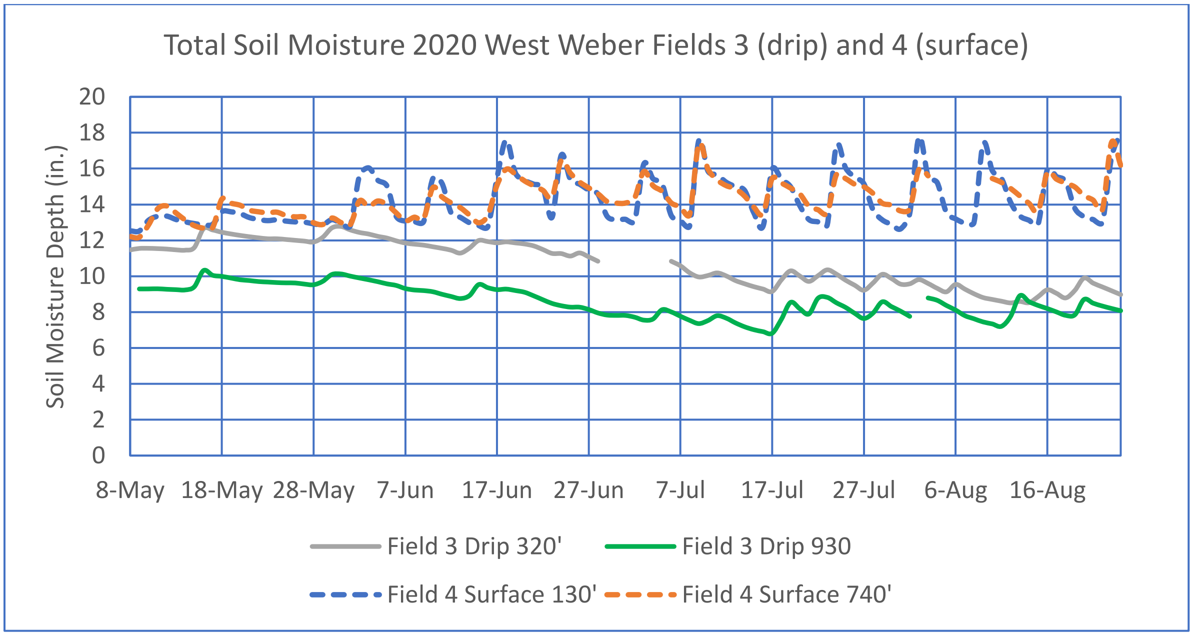


Figure 14. Daily total soil moisture for West Weber fields irrigated in 2020.

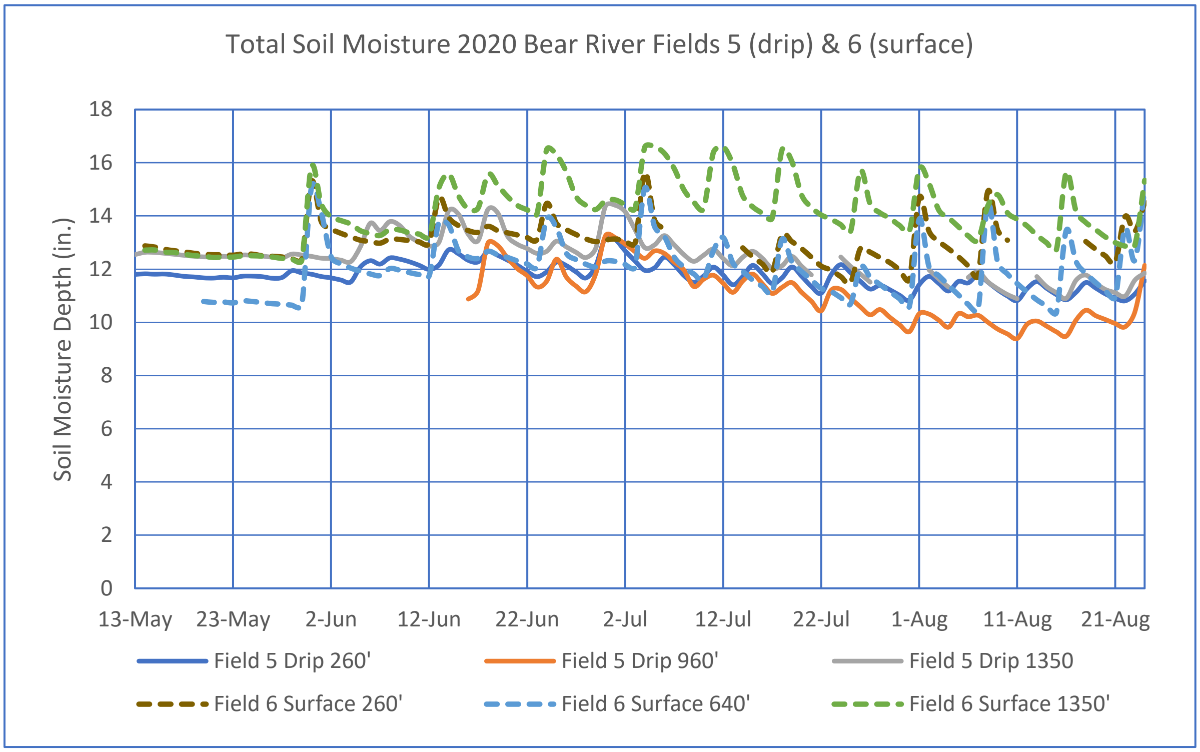


Figure 15. Daily total soil moisture for Bear River City fields irrigated in 2020.

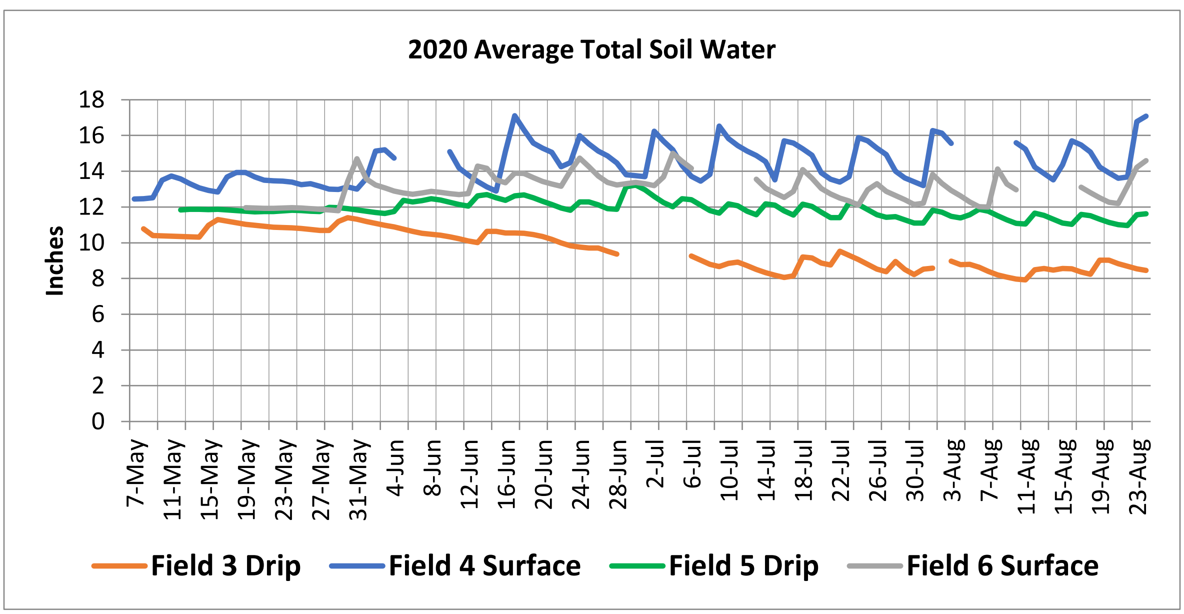


Figure 16. Average total soil water for the fields evaluated in 2020.

Onion ET

The daily crop ET estimates are based on the daily change in soil water using the soil water budget as described in the *Methodology* section. Daily changes in soil moisture result from ET, irrigation, precipitation, deep percolation, water table contribution to root zone soil moisture. Since all these variables are not measured, ET can only be calculated on days without irrigation, deep percolation, and precipitation. While gross irrigation application was measured, its distribution across a field is not uniform. Precipitation was also measured, but precipitation is infrequent and may not be different in a field that at the weather stations. Days with irrigation, precipitation, and deep percolation were excluded by comparing the daily change in soil water to a range of expected ET based on reference ET calculated from weather data. For example, if the change in soil water resulted in a daily ET that was much more than the daily reference ET, the soil was losing water from deep percolation because energy is not available to evaporate the amount of water lost from the soil. On other days the change in soil water shows a very low ET or negative ET (soil is wetter) then an irrigation occurred. After excluding these days from the analysis, an ET can be calculated for most days.

Figure 17 shows examples of the cumulative ET calculated from crop coefficients developed from this study. The surface irrigated onions have more evaporation from the soil. The ET varied from field to field and within fields and was largely a function of the available soil water. It was observed and the data supports that inadequate irrigation can occur in drip fields due to irrigation uniformity and low irrigation application. Table 4 lists the calculated ET for the periods monitored, the values are for a partial season and don't include all evaporation from the soil. The in-field variation in ET results primarily from different irrigation differences in the field

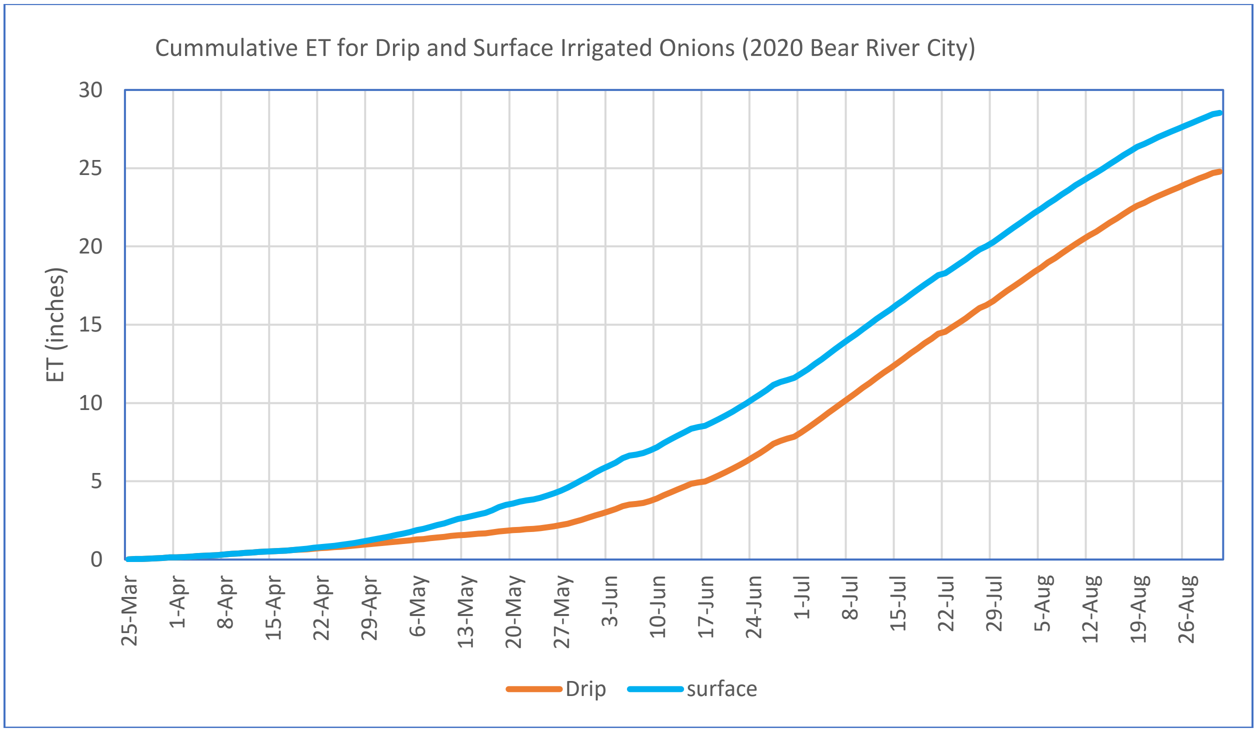


Figure 17. Example of cumulative irrigation depletions calculated from soil moisture

Table 4. ET calculated from changes in measured soil moisture (days are periods of continuous data).

Station	Beginning Measurement Date	Ending Measurement Date	Total ET	Days	Average ET (in/day)
Field 1 Drip 2019 (201)	27-Jun	18-Aug	12.8	52	0.25
Field 1 Drip 2019 (202)	19-Jun	18-Aug	12.9	60	0.21
Field 1 Drip 2019 (203)	19-Jun	18-Aug	6.3	60	0.10
Field 2 Surface 2019 (101)	28-Jun	3-Sep	15.0	67	0.22
Field 2 Surface 2019 (102)	29-Jun	4-Sep	16.5	67	0.25
Field 2 Surface 2019 (103)	26-Jun	27-Aug	13.4	62	0.22
Field 3 Drip 2020 (201)	11-May	24-Aug	18.6	105	0.18
Field 3 Drip 2020 (202)	12-May	24-Aug	15.9	104	0.15
Field 4 Surface 2020 (102)	9-May	22-Aug	22.5	105	0.21
Field 4 Surface 2020 (103)	15-May	22-Aug	19.6	99	0.20
Field 5 Drip 2020 (101)	15-May	22-Aug	18.7	99	0.19
Field 5 Drip 2020 (102)	19-Jun	22-Aug	18.1	64	0.28
Field 5 Drip 2020 (103)	15-May	22-Aug	19.6	99	0.20
Field 6 Surface 2020 (201)	15-May	20-Aug	19.1	97	0.20
Field 6 Surface 2020 (202)	21-May	20-Aug	18.8	91	0.21
Field 6 Surface 2020 (203)	16-May	21-Aug	17.9	97	0.18

The soil water measurement capture some of the evaporation from the soil as the water moves upward through the soil from wetter to drier soils. There are three shallow sensors at 4 inches depth that record some of the water loss through evaporation. The surface irrigated fields have larger changes in shallow soil moisture between irrigation due to evaporation from the soil surface.

Table 5 summarizes the total irrigation applications and the estimated depletion from irrigation and the total consumptive use (from irrigation, precipitation, and soil water depletion). The surface irrigation had more depletion due to evaporation from the soil surface and higher yields. There was more precipitation in 2019 than in 2020, resulting in similar total consumptive use but less irrigation. The irrigation on Field 2 has some uncertainty because multiple fields were irrigated from the same canal and some water spilled after the canal measurement. The applications were based on the irrigation set times provided by the grower.

Table 5. Summary of irrigation and consumptive use on evaluated fields.

Field	Year	Irrigation Method	Total Irrigation (in.)	Estimated Irrigation CU (in.)	Estimated Total CU (in.)	Notes
1	2019	Drip	14.6	14.6	19.9	Under irrigated
2	2019	Drip then Surface	96 (appr.)	21.5	31.1	Established with drip irrigation
3	2020	Drip	19.8	19.8	24.3	Some under-irrigation
4	2020	Drip then Surface	64.5(appr.)	26.1	28.8	Established with 5 drip irrigations of about 1.3 inches each
5	2020	Drip	25.1	24.0	26.7	Good crop uniformity
6	2020	Surface	52 (appr.)	25.1	27.8	Poor onion stand

Crop Coefficients

Crop coefficients (Kc) are used to estimate potential crop ET, they aid in irrigation scheduling and estimation of consumptive use. The equation is, ET_{crop} = Kc * ETo; thus Kc=ET_{crop} / ETo. Crop coefficients for all soil moisture monitoring sites were calculated and plotted based on the calculated onion ET. Crop coefficients calculate sufficient water for a good yield without water being the limiting factor. Although crop coefficients were calculated for all sites, only the sites with higher yields are used in the derivation of a crop curve (Kc v. date, days after planting, or crop growth stage) for West Weber and Bear River City. Crop coefficients are generally transferable and can be used for areas with similar climates. As an example, Figure 18 is the crop curve for onions in Fields 4 and 5. Figure 19 is the recommended Kc for onions. The dates for the Kc could be adjusted based on planting dates and crop development. The figure is based on the calculated Kc for onions grown in 2020 on Fields 4 (surface) and Field 5 (drip). Fields 4 and 5 had good yields, the weather in 2020 allowed for typical planting and harvest dates. The early season ET and Kc values depend on irrigation and soil water evaporation. The soil moisture data reflect some, but not all of the soil evaporation. The unaccounted soil evaporation is estimated to be about 3 inches more than the soil moisture evaporation from the drip irrigated soils. The surface irrigated fields will typically apply sufficient water each irrigation due to the nature of furrow irrigation. The irrigation requirement is crop ET, minus precipitation, plus irrigation to account for irrigation uniformity. It is recommended that the drip irrigation system apply about 10 to 20 percent additional water to account for irrigation uniformity, uncertainty, and evaporation from the soil surface. Of note is that both the drip and surface irrigated onion depleted about the same amount of water from the soil during the mid-season. The surface irrigated onions are in a cooler environment from the surface evaporation from the wetter soil.

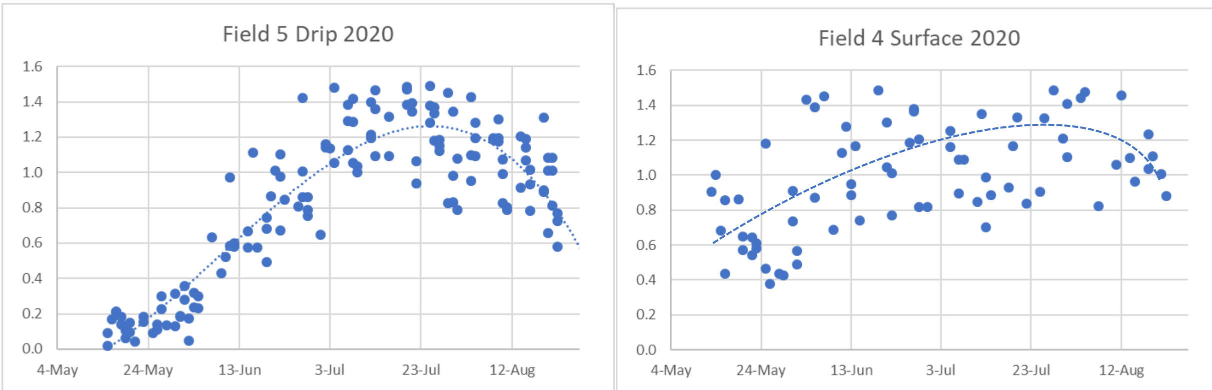


Figure 18. Example of daily Kc values calculated from soil water measurement

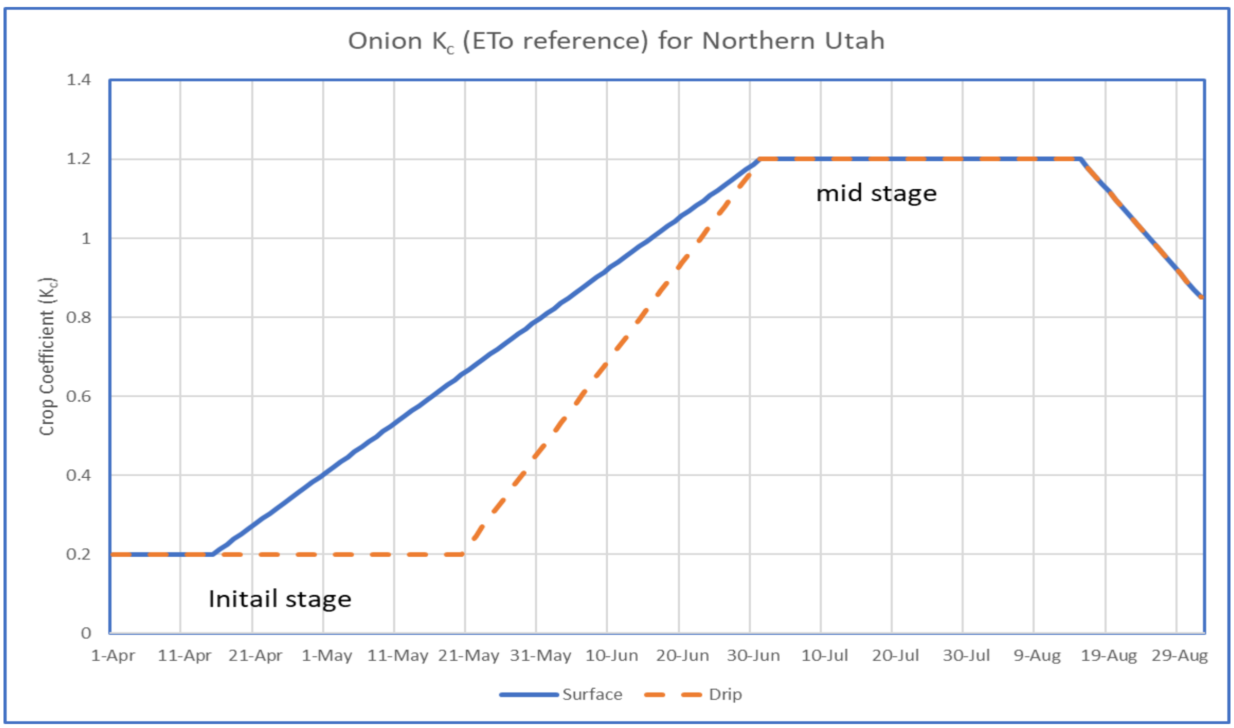


Figure 19. Recommend Kc values for northern Utah.

The Utah Climate Center provides ETo calculated from weather stations located near most irrigated agricultural areas in Utah. The data is available online and weather stations can be located on a map with the data being accessible in multiple formats (https://climate.usu.edu/). The website provides the data that can be used with crop coefficients to calculate estimated soil depletion and crop water needs. There are two reported reference ET values ETr and ETo, it is important to use the ETo, which is the smallest of the two values for the presented crop coefficients.

Soil Water Evaporation

Surface irrigation wets nearly the entire soil surface while drip irrigation wets only the onion bed. The cooler soil surface temperatures of surface irrigation result from the evaporation of water from the wet soil in the furrows and on the onion beds. At the beginning of the season when the onions are small and transpiration is low the soil water evaporation is the largest component of ET after a surface irrigation event. This is reflected in the Kc differences between surface and drip irrigated soil during the development of the onion canopy. Preliminary analysis shows that surface irrigation soil evaporation can be about 3 inches more than that of drip irrigated. The data shows that after the onions leaf canopy is well developed the ET rate of drip and surface are about the same. This may be due to the drier soil in drip irrigated onions resulting in higher surface temperatures that may impact the transpiration rate of the onions.

Another soil water evaporation aspect of drip irrigation is that the equipment turning areas (about a 15-foot strip) at the ends (head and tail) of the field are not irrigated. This reduces the irrigated area by 3 to 5 percent, saving water lost to evaporation from wet soils. This is an additional reduction in depletion. It can also reduce weeds in the turning areas of the field.

Onion Yield

Onions yields are dependent on the interaction of many variables, such as soils, seedbed preparation, weather (temperature, precipitation, hail storms, etc.), planting dates, seed germination rate, onion variety, plant population rate, fertility, weeds, pests, diseases, harvest dates, irrigation amounts, and schedule, etc. In some cases drip irrigation provides greater yields and returns due to more precise water management capabilities, better germination, and establishment, increased ability to conduct field operations as needed due to drier furrows, lower fertilizer needs, more uniform irrigation resulting in more uniform onion growth and size.

Tables 6-11 show the yield sampling results for the drip and surface irrigated fields. Each field location sample is the average of three yield samples taken from 6 feet of the onion beds near the sensor. The exception is Field 1 which had samples taken in the top third, middle, and bottom third of the field onion beds on rows near the soil moisture sensors. The yields include onion yield weight and bulb count by bulb size. In 2019, the fields were planted and harvested at different dates and had different onion varieties. The two highest yielding fields were surface irrigated field, but drip irrigation was used to help germinate and establish the onions. The yields are an important factor, but not the primary objective of the study is to determine the difference in water depletion.

Figure 20 shows the onion yields and bulb counts by paired by season and location for drip and surface irrigation. The first pair on left is 2019 in West Weber, the middle pair is 2020 in West Weber, and the last pair is 2020 in Bear River City. The surface irrigated onion yields were greater than the drip irrigated onion yields in West Weber and the drip irrigated onions yields were greater than the surface irrigated yields in Bear River City. Figure 21 shows show onion bulb count (bulbs per acre) and yield. There is a relationship between bulb count and yield, however, good yield can be achieved or a range of bulb counts.

Table 6. Field 1 2019 yields from drip irrigated onions.

Field 1 Drip Irrigation							
Field Location	Units	Onion bulb diameter (inches)					
		<2.25	3	3.5	4	4.0+	Total
North	bulbs/ac.	3,909	33,508	65,898	26,806	2,792	132,914
	lbs./ac.	1,059	17,511	53,418	27,313	3,300	102,601
Middle	bulbs/ac.	4,468	43,560	36,300	29,040	2,234	115,602
	lbs./ac.	837	21,624	28,298	28,396	2,881	82,036
South (not sampled)	bulbs/ac.						
	lbs./ac.						
Drip Irrigation Average	bulbs/ac.	4,188	38,534	51,099	27,923	2,513	124,258
	lbs./ac.	948	19,567	40,858	27,854	3,091	92,319
	bags/ac.	19.0	391.3	817.2	557.1	61.8	1,846.4
	% size	3.4%	31.0%	41.1%	22.5%	2.0%	

Table 7. Field 2 2019 yields from surface irrigated onions.

Field 2 Surface Irrigation							
Field Location	Units	Onion bulb diameter (inches)					
		<2.25	3	3.5	4	4.0+	Total
North	bulbs/ac.	12,286	53,612	66,457	44,677	2,234	179,266
	lbs./ac.	1,958	26,697	49,355	44,134	3,103	125,246
Middle	bulbs/ac.	13,962	35,742	64,223	53,054	5,026	172,006
	lbs./ac.	2,734	16,279	54,330	48,468	7,093	128,904
South	bulbs/ac.	7,260	21,780	57,522	52,495	13,403	152,460
	lbs./ac.	2,044	11,157	40,833	55,660	18,126	127,820
Surface Irrigation Average	bulbs/ac.	11,169	37,045	62,734	50,075	6,888	167,911
	lbs./ac.	2,245	18,044	48,173	49,420	9,441	127,323
	bags/ac.	44.9	360.9	963.5	988.4	188.8	2,546.5
	% size	6.7%	22.1%	37.4%	29.8%	4.1%	

Table 8. Field 3 2020 yields from drip irrigated onions.

Field 3 Drip Irrigation (2020)							
Field Location	Units	Onion bulb diameter (inches)					
		<2.25	3	3.5	4	4.0+	Total
East	bulbs/ac.	14,892	49,889	61,803	8,191	-	134,775
	lbs./ac.	2,904	19,137	35,816	7,148	-	65,005
Middle	bulbs/ac.	2,978	32,018	93,077	19,360	-	147,434
	lbs./ac.	670	13,478	57,261	15,711	-	87,120
West	bulbs/ac.	745	14,148	81,908	43,932	-	140,732
	lbs./ac.	149	5,212	55,772	38,869	-	100,002
Drip Irrigation Average	bulbs/ac.	6,205	32,018	78,929	23,828	-	140,981
	lbs./ac.	1,241	12,609	49,616	20,576	-	84,042
	bags/ac.	24.8	252.2	992.3	411.5	-	1,680.8
	% size	4.4%	22.7%	56.0%	16.9%	0.0%	

Table 9. Field 4 2020 yields from surface irrigated onions.

Field 4 Surface Irrigation (2020)							
Field Location	Units	Onion bulb diameter (inches)					
		<2.25	2.25 to 3	3 to 3.5	3.5 to 4	4.0+	Total
East	bulbs/ac.	10,425	16,382	31,274	62,548	26,806	147,434
	lbs./ac.	1,862	6,627	19,434	60,463	34,997	123,383
Middle	bulbs/ac.	11,169	8,191	46,911	61,803	25,317	153,391
	lbs./ac.	2,457	3,425	30,231	56,144	30,678	122,936
West	bulbs/ac.	14,148	17,126	50,634	52,123	10,425	144,455
	lbs./ac.	2,681	7,818	35,667	48,177	12,658	107,001
Surface Irrigation Average	bulbs/ac.	11,914	13,899	42,939	58,825	20,849	148,427
	lbs./ac.	2,333	5,957	28,444	54,928	26,111	117,773
	bags/ac.	46.7	119.1	568.9	1,098.6	522.2	2,355.5
	% size	8.0%	9.4%	28.9%	39.6%	14.0%	

Table 10. Field 5 2020 yields from drip irrigated onion field.

Field 5 Drip Irrigation (2020)							
Field Location	Units	Onion bulb diameter (inches)					
		<2.25	3	3.5	4	4.0+	Total
East	bulbs/ac.	5,212	12,658	25,317	64,037	29,785	137,009
	lbs./ac.	1,117	4,244	16,158	60,388	35,667	117,575
Middle	bulbs/ac.	6,702	11,169	21,594	37,975	37,231	114,671
	lbs./ac.	1,042	5,212	15,711	37,380	49,591	108,937
West	bulbs/ac.	3,723	8,935	18,615	50,634	29,040	110,948
	lbs./ac.	670	3,946	13,999	50,113	36,858	105,586
Drip Irrigation Average	bulbs/ac.	5,212	10,921	21,842	50,882	32,018	120,876
	lbs./ac.	943	4,468	15,289	49,294	40,706	110,699
	bags/ac.	18.9	89.4	305.8	985.9	814.1	2,214.0
	% size	4.3%	9.0%	18.1%	42.1%	26.5%	

Table 11. Field 6 2020 yields from surface irrigated onions.

Field 6 Onion Yield Surface Irrigation (2020)							
Field Location	Units	Onion bulb diameter (inches)					
		<2.25	3	3.5	4	4.0+	Total
South	bulbs/ac.	10,611	27,923	37,417	22,338	3,909	102,198
	lbs./ac.	1,675	10,722	23,623	19,602	5,194	60,816
Middle	bulbs/ac.	2,792	26,806	28,482	26,806	7,818	92,705
	lbs./ac.	503	10,220	22,897	23,400	9,550	66,569
North (top)	bulbs/ac.	6,702	26,062	55,102	24,572	2,978	115,415
	lbs./ac.	1,117	11,095	35,220	21,743	3,798	72,972
Surface Irrigation Average	bulbs/ac.	6,702	26,930	40,333	24,572	4,902	103,439
	lbs./ac.	1,098	10,679	27,247	21,581	6,180	66,786
	bags/ac.	22.0	213.6	544.9	431.6	123.6	1,335.7
	% size	6.5%	26.0%	39.0%	23.8%	4.7%	

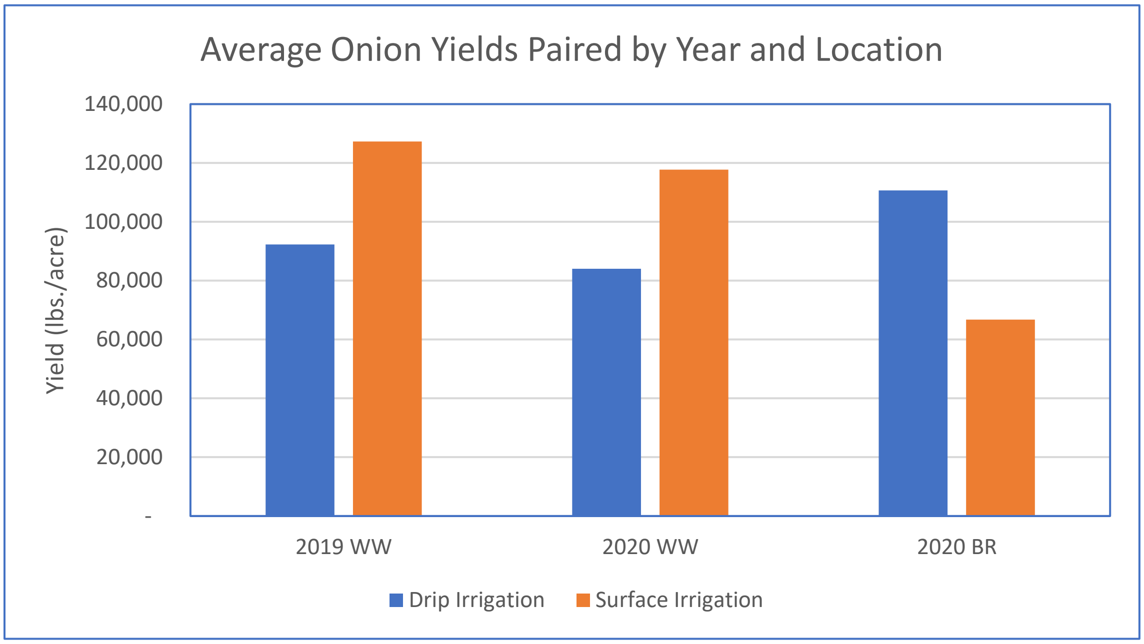


Figure 20. Onion yield with data paired by season and location.

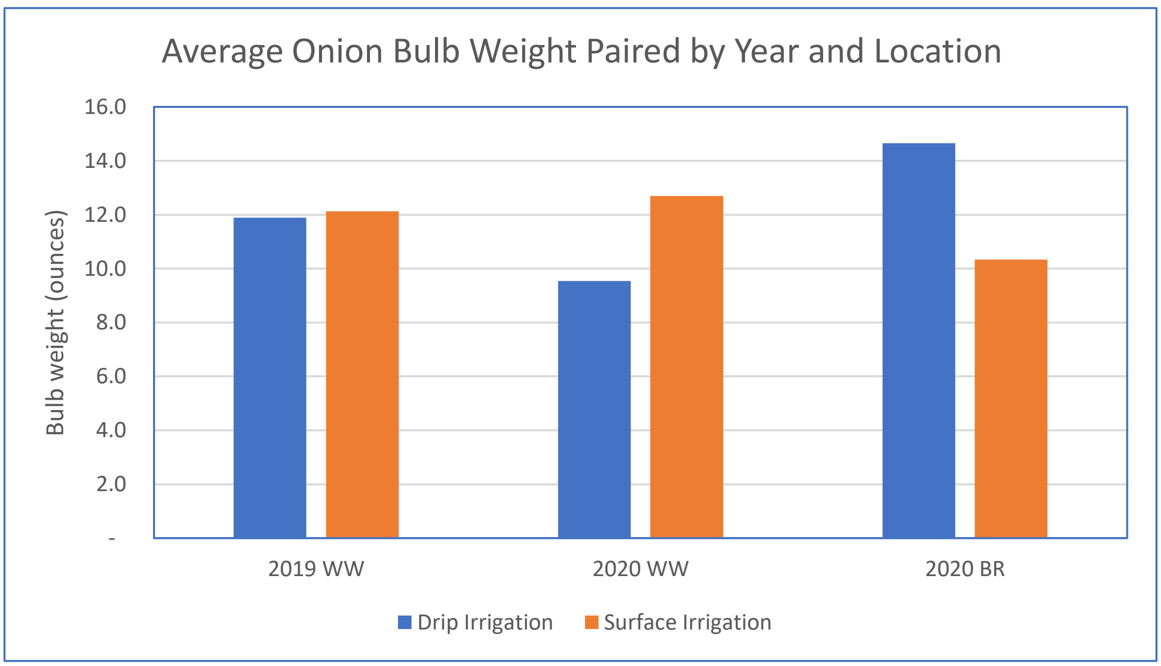


Figure 21. Onion bulb count (bulbs per acre) paired by season and location.

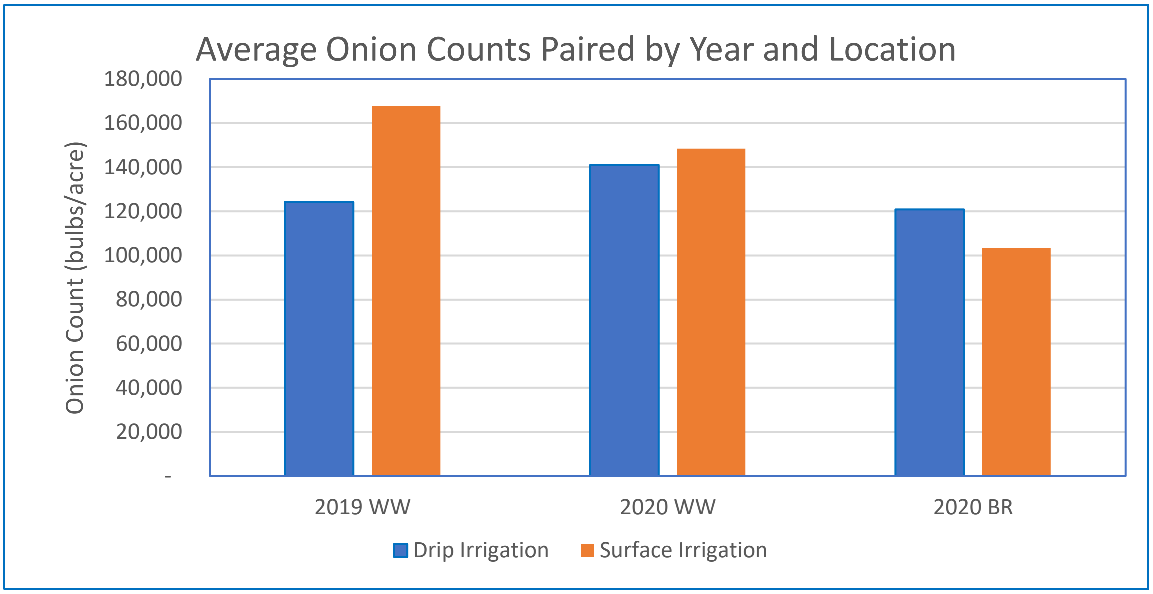


Figure 22. Average bulb weight paired by season and location.

Figure 23 shows yield and bulb count by field sample location. There is not a strong relationship between bulb count and bulb weight, but the largest bulbs weights occurred at a bulb count of about 112,000 bulbs per acre. Field 2 had about the same yield for bulb counts from about 150,000 to 180,000 which was reflected in the bulb weight. Figure 24 shows onion bulb weight v. onion bulb count per acre by field sample locations. Figures 25 and 26 show the bulb size distribution for the fields in the study. Bulb size distribution results from many input variables. The drip irrigation in Field 5 had the largest percentage of bulbs over 3.5 inches at about 68%.

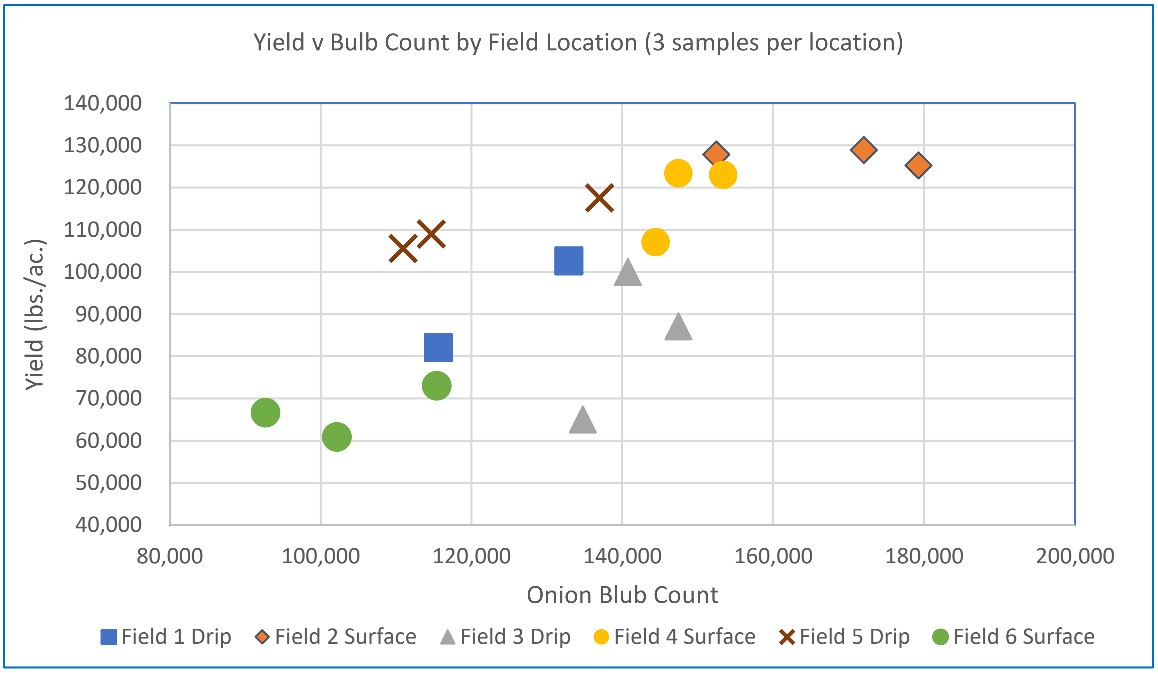


Figure 23. Yield v. bulb count per acre by field sample location.

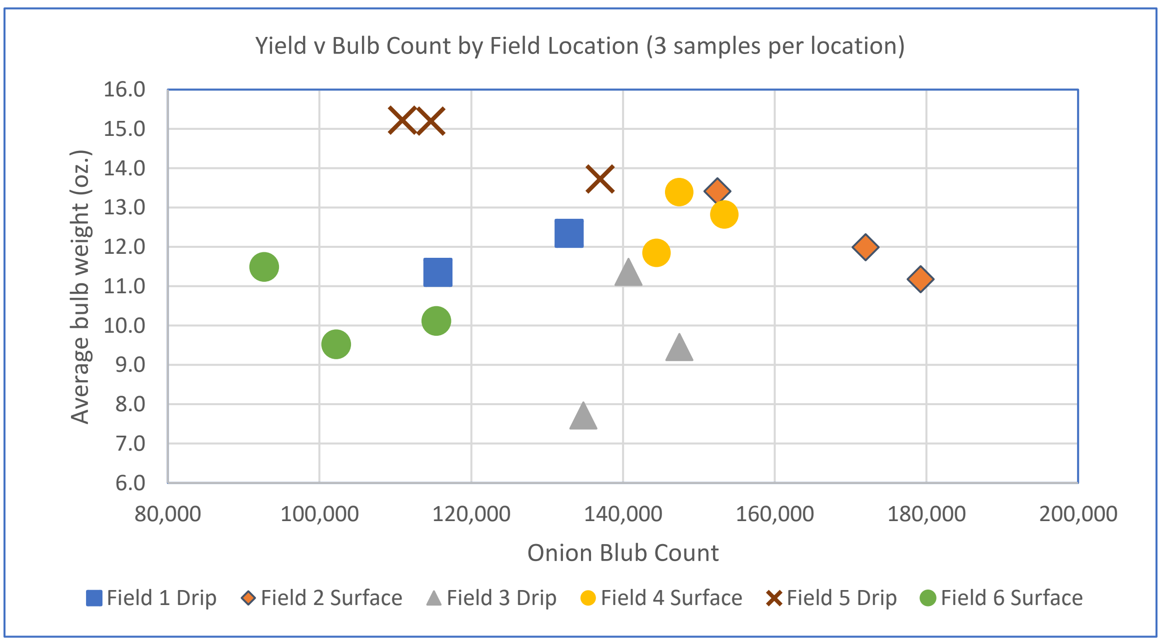


Figure 24. Onion bulb weight v. onion bulb count per acre by field sample locations.

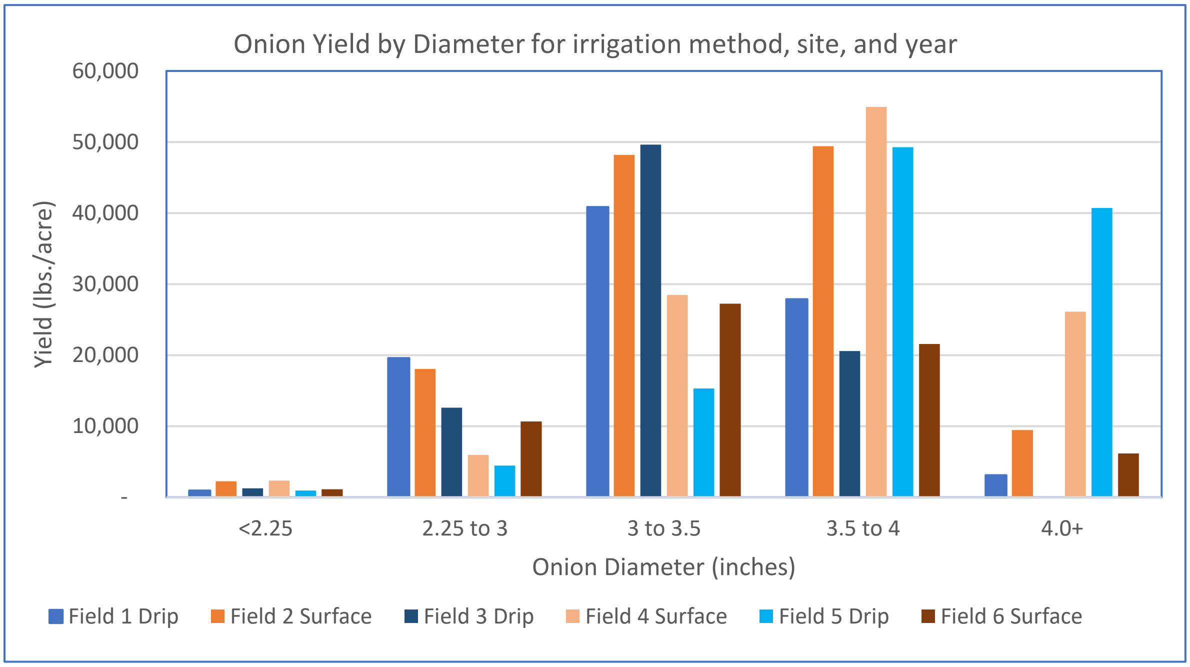


Figure 25. Yield distribution of onions based on bulb diameter in inches by fields.

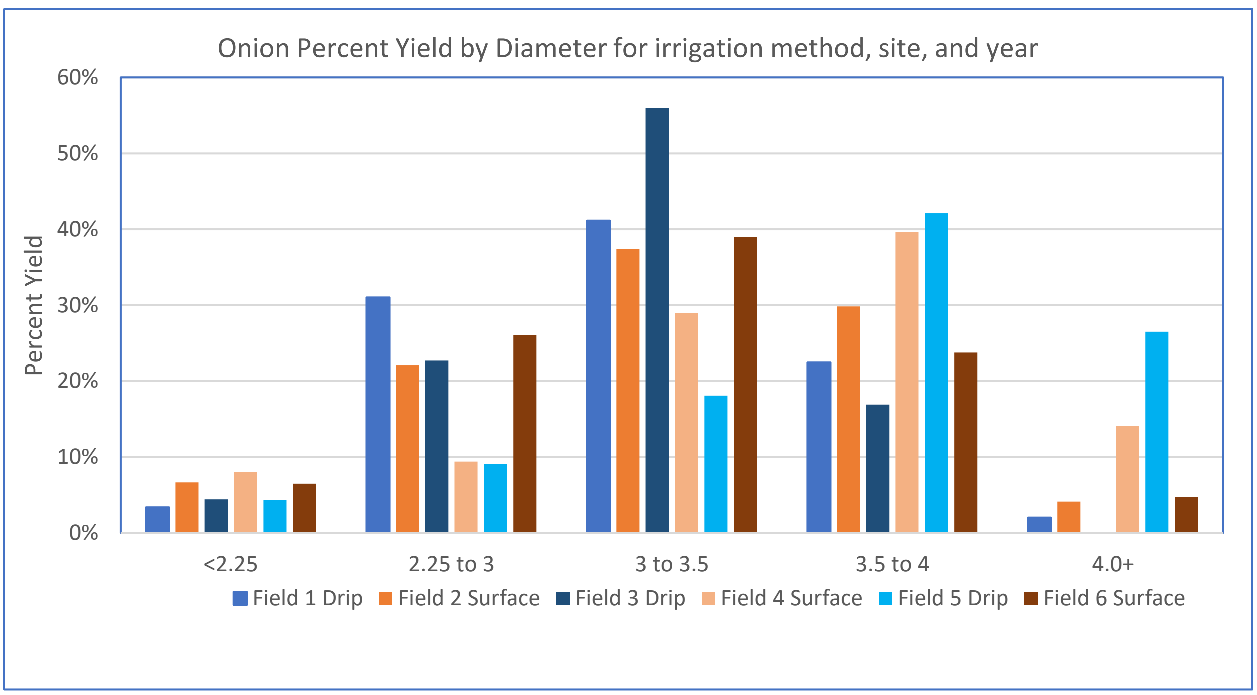


Figure 26. Distribution of onion bulb size (diameter in inches) by fields.

Effect of Irrigation Uniformity on Yield

Irrigation and irrigation uniformity (measured by soil moisture and observed from NDVI images of the fields) have an impact on yield. The data shows that the yields for two of the three surface irrigated fields were better than those of the drip irrigated fields. The yield differences by field location were observed from the yield data and then verified by 10 by 10-meter resolution of the Sentinel-2 satellite imagery used by OneSoil (free application for precision farming) to calculate Normalized Difference Vegetative Index (NDVI) (OneSoil, 2021). NVDI is an indicator of vegetation biomass and greenness. NDVI is calculated from near-infrared and red (visual) electromagnetic spectrum and is equal to (NIR - red)/(NIR + red) resulting in a value between -1 and 1, however, the values for crops are between 0 and 1. With 1 having the most biomass on the ground surface.

The drip irrigation uniformity is higher than other irrigation systems. The design coefficient of uniformity of the drip systems is about 90 percent. In simple terms, one-quarter of the field area receives 10 percent more water than the average application, and one-quarter of the area receives less than10 percent of the average. In a drip system with non-pressure compensating emitters, the different pressure on the drip tubing causes the different application amounts. Pressure differences result from friction/head loss in the manifold (lay flat tubing at the head of the field) and the laterals (drip tubing), and ground elevation differences in a field. The irrigation coefficient of uniformity is important to consider in managing a drip irrigation system. Under irrigation results in low yields in a portion or all the field. Excessive irrigation requires more inputs but doesn't increase yields.

Figure 27 shows the yields from drip irrigated fields based on sample locations in relationship to the distance (drip manifold and drip) from the field inlet. For the drip irrigated fields, the pressure loss in the manifolds and drip tape resulted in lower water application and lower yields for the locations furthest away from the field irrigation input location. The yield difference low-to-high in Field 2 was 35,000 lbs. per acre. This is a result of irrigation uniformity and under irrigation of most of the field. A few pounds per square inch (psi) difference in a drip system without pressure compensating emitters results in a significant impact on water application. For example, a pressure range of 8 to 12 psi results in a 25 percent difference in application rate. Figure 28 shows the yields from surface irrigated onions in relationship to distance from the top of the field (water inlet). The differences in the yield are less for the surface irrigated than for drip irrigated fields because the root zone in the surface irrigated field is generally filled with each irrigation. The surface irrigated fields receive 2 to 3 times more water than the drip irrigated fields. Figures 29 through 37 show the yield sampling location, the NDVI before dry-down of the onions, and modeled irrigation uniformities. The NDVI corresponds with yields based on a visual assessment of the images.

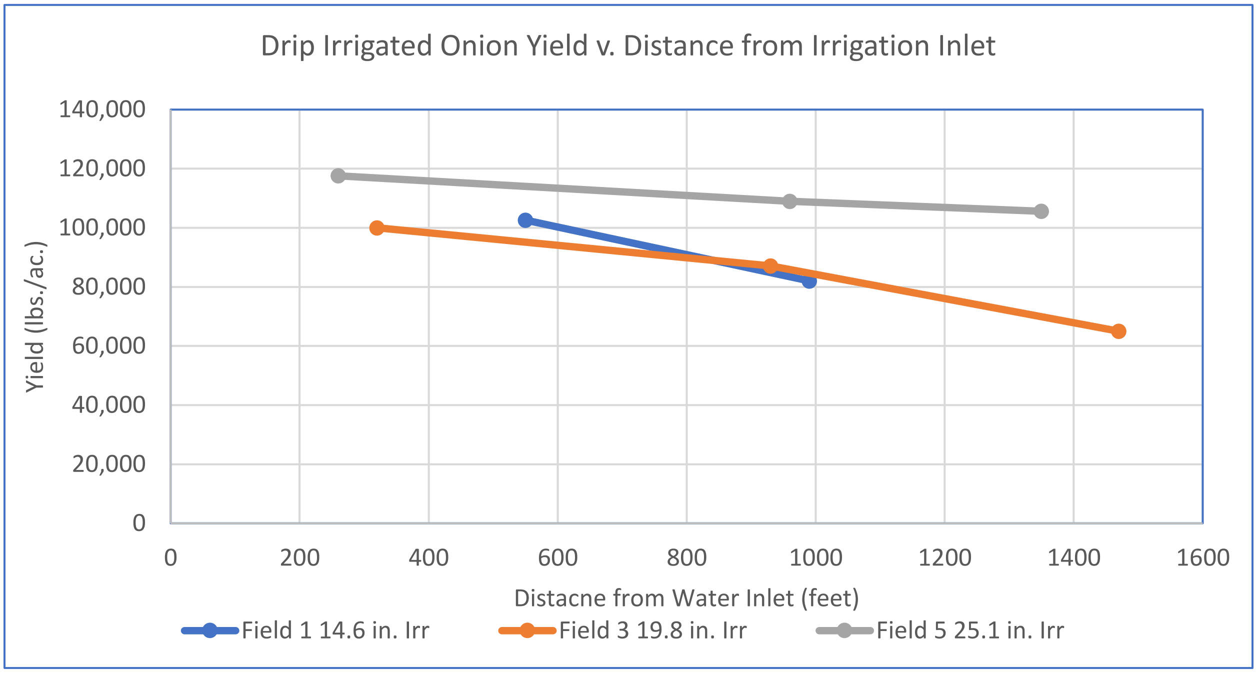


Figure 27. Yield versus distance from water inlet for drip irrigated onions.

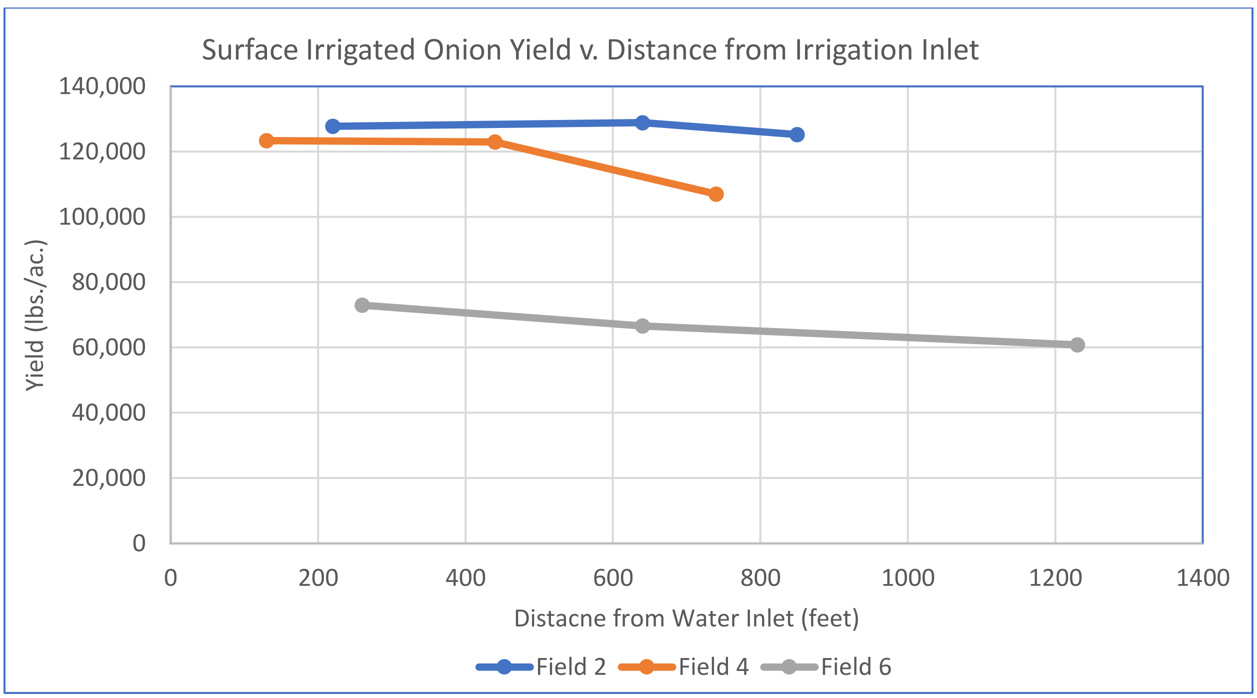


Figure 28. Yield versus distance from water inlet for surface irrigated onions.

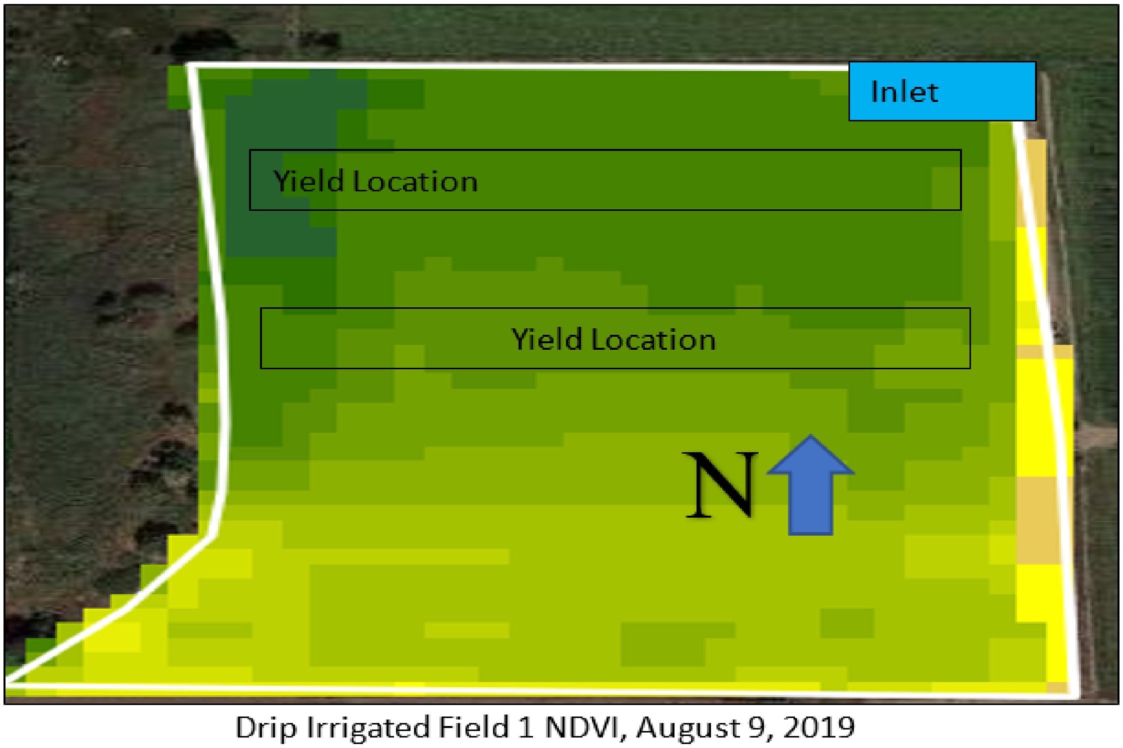


Figure 29. NDVI for Field 1 obtained from OneSoil.

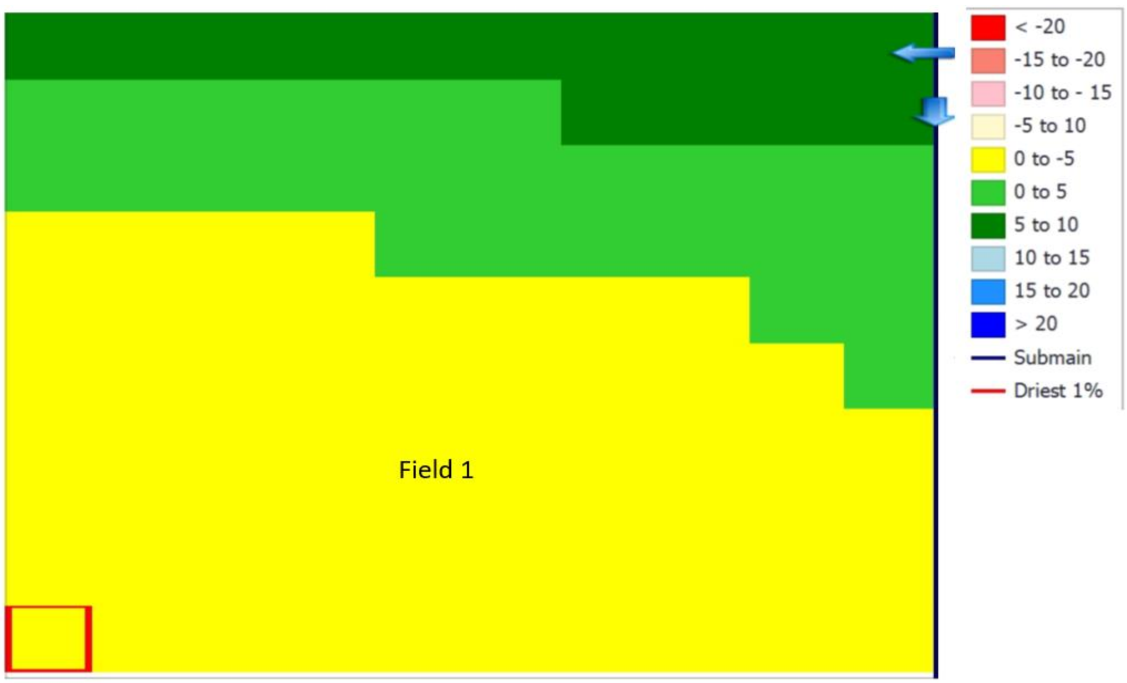
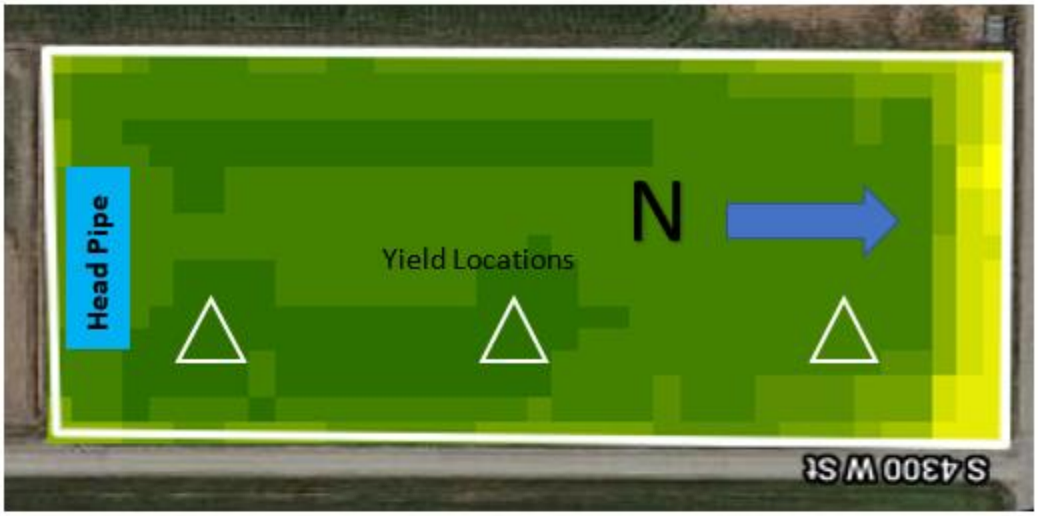
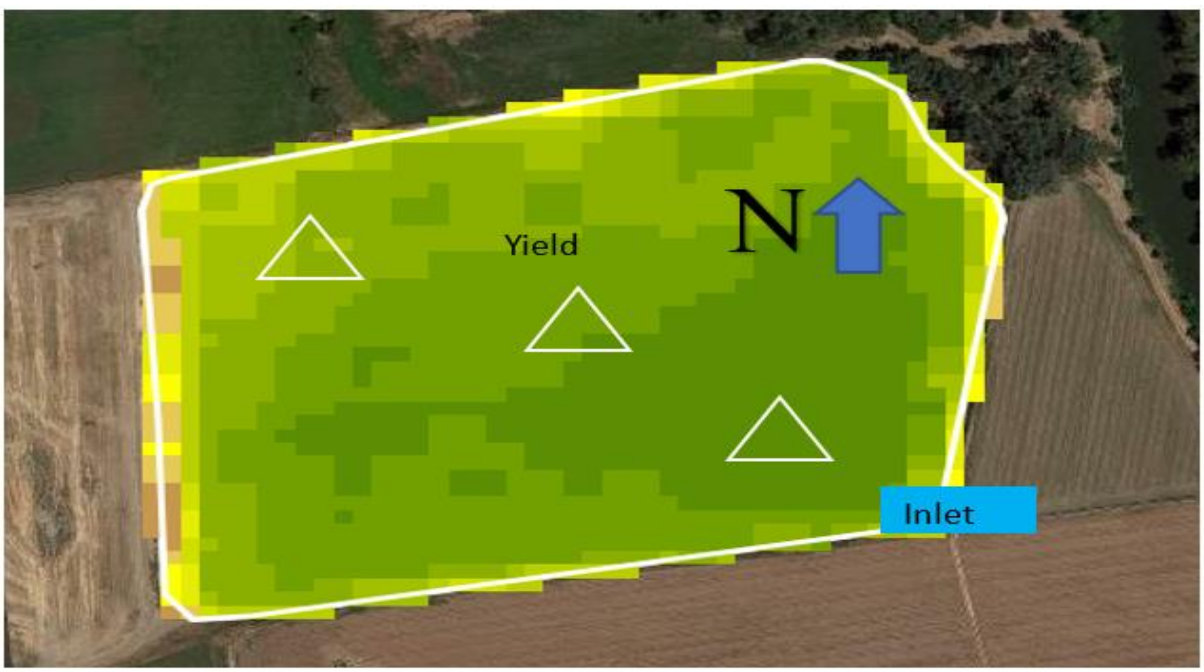


Figure 30. Modeled irrigation uniformity for Field 1.



Surface Irrigated Field 2 NDVI August 13, 2019

Figure 31. NDVI for Field 2 obtained from OneSoil.



Drip Irrigated Field 3 NDVI, August 13, 2020

Figure 32. NDVI for Field 3 obtained from OneSoil.

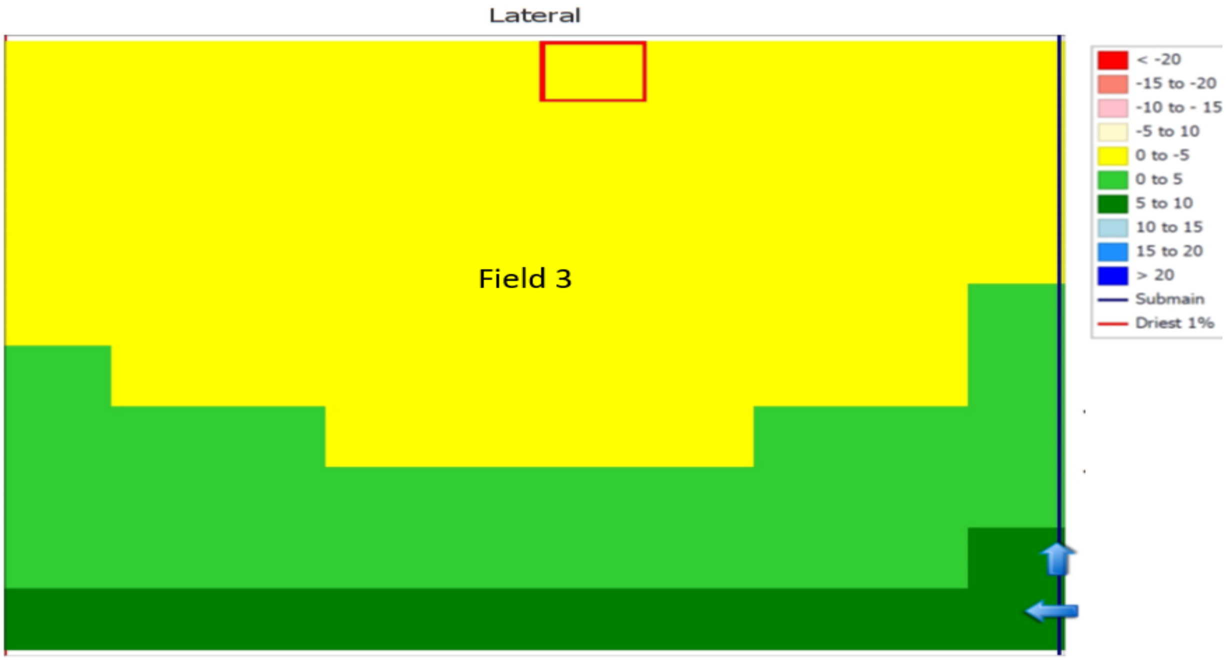
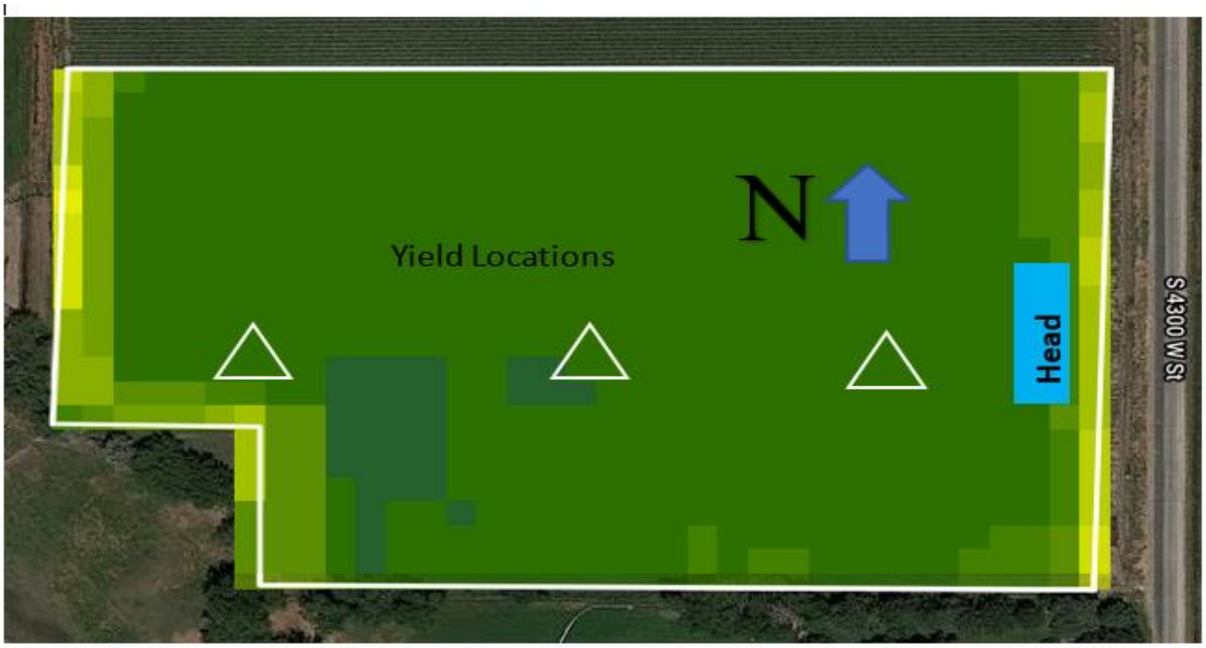


Figure 33. Modeled irrigation uniformity for Field 3.



Surface Irrigated Field 4 NDVI August 13, 2020

Figure 34. NDVI for Field 4 obtained from OneSoil.

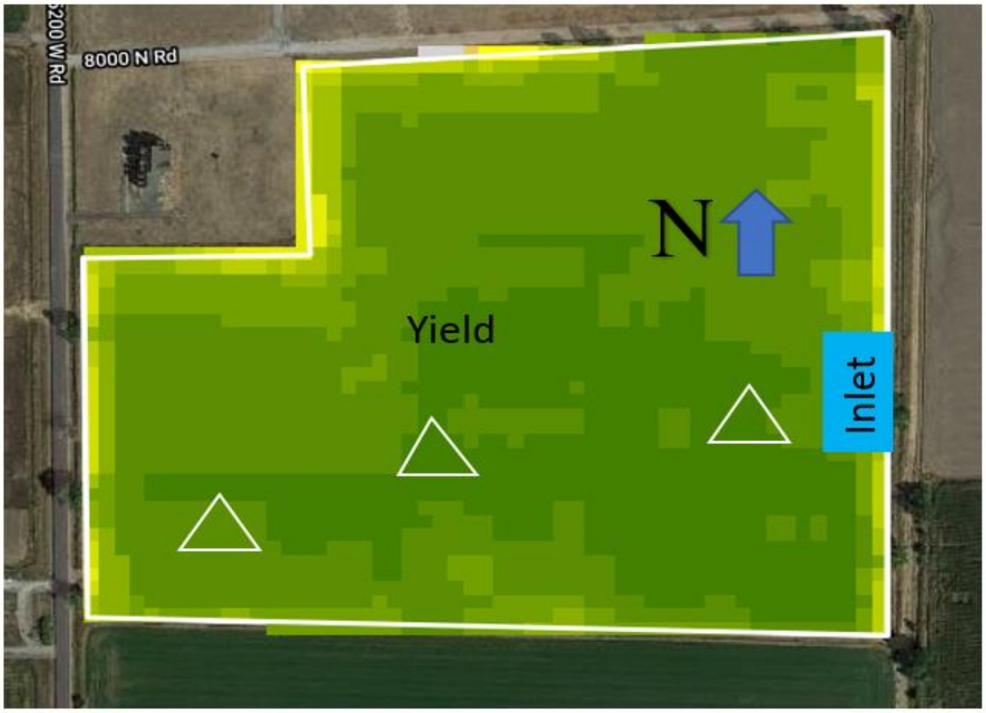


Figure 35. NDVI for Field 5 obtained from OneSoil.

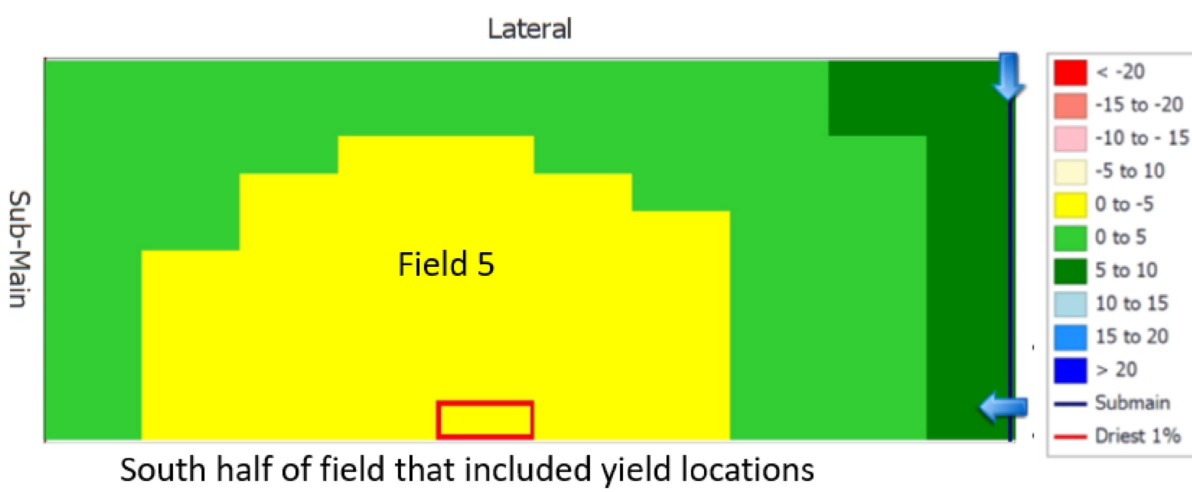


Figure 36. Modeled irrigation uniformity for south half of Field 5.

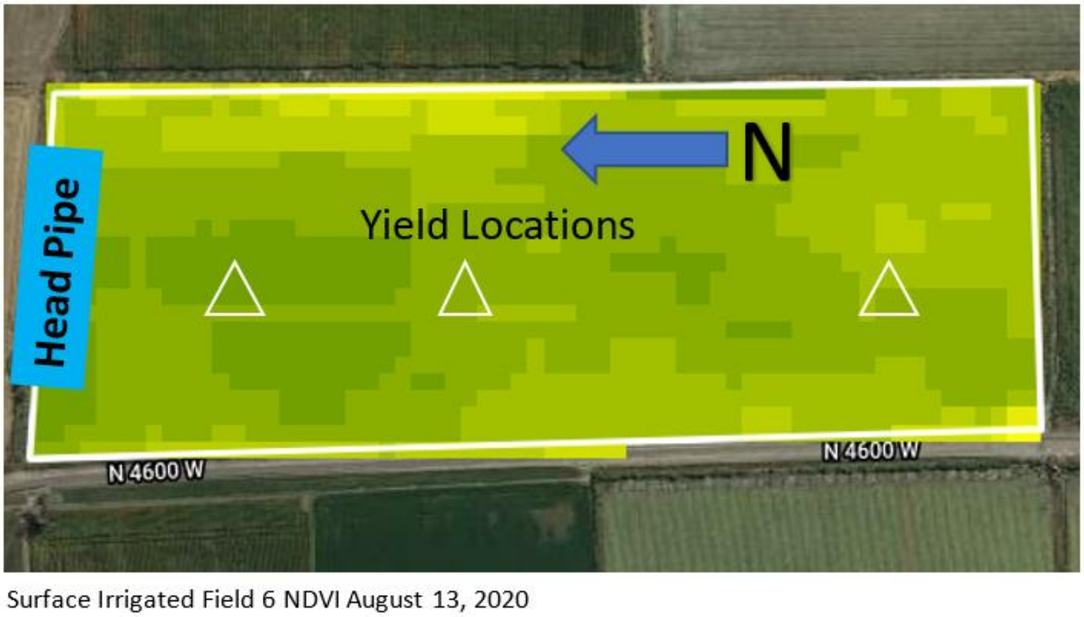


Figure 37. NDVI for Field 6 obtained from OneSoil.

An important lesson learned from the study is that drip irrigation like all irrigation doesn't apply water with perfect uniformity. This statement is not only based on yield and soil moisture data from the drip irrigated fields studied, but on other studies, irrigation scheduling, and the design specification of drip irrigation. Even with the high coefficient of uniformity of drip irrigation systems, it is advisable to use an irrigation efficiency of 90 percent which adds about 11 percent more water than the crop needs to account for the non-uniform application of water.

Water Quality Considerations

The effect of drip irrigation on water quality is also an important consideration. A few water samples were taken during the 2020 irrigation season, listed in Table 12. The data is limited and not a continuous record, however, a few observations can be made that support expected results. The drain water total dissolved solids (TDS) in West Weber are about 54 percent higher than the canal irrigation water (TDS of 677 mg/L for drains v. TDS of 440 mg/L for ditches). The Bear River sites did not have any runoff. In all but one case the TDS was higher for the runoff than the inflow. Nitrate-Nitrogen levels are higher in drain water and runoff than in irrigation water. Only one sample was taken during a fertigation event and the Nitrate-Nitrogen level was 8.2 mg/L. In general drain water from seepage has a higher TDS than surface runoff from an irrigated field. Often as drain flows diminish due to decreased runoff the TDS goes higher, but the total dissolved solids carried in the drain water may decrease. Figure 38 shows equipment used for the fertigation of onions irrigated with surface and drip methods.

Table 12. Water quality data at or near the onion fields that were sampled in 2020.

Collection Date	Water Sample	conductance		TDS mg/L	F°	Nitrate-Nitrogen mg/L
		uS/cm	specific uS/cm			
6/26/2020	Bear River Drip	884	909	591	74.5	0.42
6/26/2020	Bear River Flood Inflow (during fertigation)	667	725	471	69.5	8.28
6/26/2020	Bear River Flood (ponded at end of the field)	788	756	491	81	6.1
7/27/2020	Bear River Drip	808	821	534	75.5	0.27
8/4/2020	Bear River Drip	816	825	536	76	
8/8/2020	Bear River Flood Inflow	808	849	552	72.4	
8/8/2020	Bear River Flood (ponded at end of the field)	885	925	601	73	
6/26/2020	West Weber Drip	619	655	426	71.8	<0.20
6/26/2020	West Weber Flood Inflow	832	753	489	86.9	0.41
6/26/2020	West Weber Flood Outflow	785	749	487	81.3	1.12
7/15/2020	West Weber Drain	975	1040	676	71	2.04
7/27/2020	West Weber Drip	642	682	444	71.4	<0.20
8/3/2020	West Weber Drip	598	636	413	71.4	
8/8/2020	West Weber Drain	973	1042	677	70.8	
8/8/2020	West Weber Flood Inflow	604	656	426	69.5	
8/8/2020	West Weber Outflow	693	688	448	77.6	

Figure 38. Fertigation equipment for surface and drip irrigation.

Soil Temperature Considerations

Another observation that may have an impact on yield is the soil temperature increase under drip irrigation due to the dry furrows. During the early growth stages of the onions, the surface temperatures of the drip fields were often 10 °F hotter than the surface fields. In the early mornings, the minimum surface temperatures were about the same for both drip and surface irrigated fields. This may not be an issue because good yields were obtained in both drip and surface irrigation systems. In some crops like corn, the warmer soils in the early growth periods may help in establishing and growing crops.

Summary of Findings

The findings are based on a study of three drip and three surface irrigated onion fields. Two fields were evaluated in 2019 and four fields in 2020. High onion yields are dependent on many factors, in this study adequate soil moisture and onion stands of between 145,000 (4.4-inch spacing between onions) and 180,000 (3.6-inch spacing) plants per acre were important. High yields were obtained in both drip and surface irrigated onions. The soil moisture was maintained at higher levels with surface irrigation than with drip irrigation. As a result, the two highest yielding fields were surface irrigated. The drip irrigated field with excellent yield resulted from maintaining uniform and adequate soil moisture through proper irrigation scheduling. The other drip irrigated fields had lower soil moisture levels during the season resulting in lower and non-uniform yields. The surface irrigation had field diversions that are a least twice as high as the total irrigation with drip irrigation. The soil moisture levels in the surface irrigated field decreased more than for drip between irrigations but were still higher than the drip irrigated fields before irrigation.

Drip irrigation has the following benefits.

- Provides the capability to establish onions with uniform germination and good stands. The highest yielding fields were established with drip irrigation, even though the drip system was not used after establishment. The germination uniformity was poor and the onion stand was low in the surface irrigated field that did not use drip for establishment.
- Provides excellent irrigation and fertilization management capabilities. The results in using less fertilizer and improves area water quality due because irrigation runoff flows are eliminated and deep percolation is minimized.
- The furrows remain drier providing more opportunities for field operations such as cultivating and spraying.
- Reduces irrigation labor requirements during the irrigation season.
- Requires about half the diversions of surface irrigated onions. This is critical when water supplies are limited or water is needed for other crops or uses.
- Reduces depletion about 0.25 to 0.4 acre-feet per acre for equivalent yields, with most of the reduced depletion occurring in May and June.

- The equipment turning areas (about a 15-foot strip) at the ends of the field are not irrigated. This reduces the irrigated area by 3 to 5 percent, saving water lost to evaporation from wet soils. This is an additional reduction in depletion.
- Irrigation requirements for a well-designed and managed drip system are about 26 inches during the May through August period. They can vary due to precipitation and temperatures.
- Based on the fields evaluated, the onion yield per unit of water applied is about twice that of surface irrigation.

Disadvantages and obstacles of drip irrigation, including.

- Drip can be used to apply small precise amounts of water and as a result under irrigation and/or irrigation non-uniformity can easily occur resulting in low yields. This limitation can be addressed by good drip system design, applying enough water to account for non-uniformities in irrigation, and irrigation scheduling.
- The cost of the drip system and the energy requirements. These costs can be offset by improved onion yields resulting from the better establishment, reduced fertilizer costs, uniform onion bulb size, less water application (provides water for other crops). The improved onion yields are based on good irrigation system design and irrigation scheduling.
- Require time for installation, setup, and removal.

Limitations to the implementation of drip irrigation, include.

- Water availability from a timing perspective can prevent proper irrigation scheduling and limit irrigation time. Most irrigation water-turn rotation schedules limit the use of drip irrigation systems that are dependent on having water more frequently and for longer periods than provided by the water rotation schedule.
- The cost and land required to build an on-farm water storage reservoir so that irrigations can occur on-demand as drip irrigations are needed.

Crop coefficients were developed that can be used for irrigation scheduling and estimating irrigation water use. The total consumptive water use of drip irrigated onions with high yields was about 25 inches, while the surface irrigated onions was about 30 inches. These values are not field averages, but the highest yielding locations. Drip irrigation diversion requirements are less than half that of surface irrigation and reduce consumptive use by about 20 percent. Drip irrigation of onions and row crops can help optimize agriculture water use, but drip irrigation system design, installation, and operation are needed for good yields. Providing tools and information on drip irrigation scheduling (when and how much to irrigate) is needed to optimize yields and returns on investments. Irrigation scheduling on surface irrigation is fixed by the irrigation turns and is less critical because the soil water is fully replenished each irrigation.

Recommendations

The research shows that drip irrigation reduces irrigation diversions, consumptive use, fertilizer use, and labor. However, with adequate irrigation water availability, surface irrigation costs slightly less, and good yields can be produced. However, drip irrigation is better for establishing the onions. The following items would encourage the use of drip irrigation.

- A major impairment to increasing drip irrigation season-long use and improving irrigation efficiency is the water supply delivery capabilities of the canal systems. Piping canals and laterals are expensive, but the downstream water control at the turnouts makes it much easier to provide water to users on demand. Likewise or automating ditch systems is expensive, but can help an open canal system deliver water more efficiently and provides more flexibility in delivery quantities and timing.
- A cost-share program to provide funding to help encourage the use of drip irrigation. Funding for incentives can be difficult to obtain, but reduced consumptive use and diversions provide a great benefit to the state. A system would also need to be in place so that decreased diversions and reduced CU is available for alternative water uses that benefit the funders.
- Provide education on the best management practices, soil moisture monitoring, and irrigation scheduling for drip irrigation systems so that good yields are obtained. This education can be from grower-to-grower, consultants, and industry experts, or Extension educators.
- Provide irrigation water delivery flexibility so that producers can use their water shares in different locations to increase total production.

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Section 2 - Economic Returns in Onion Production under Drip and Furrow Irrigation Systems

Introduction

In 2015, irrigation was responsible for 42% of all fresh water withdrawals in the United States (U.S.) (Dieter et al., 2018). The Conterminous Westerns States, including Utah, accounted for 81% of fresh water withdrawals for irrigation purposes, which is a reflection of the arid climate in these states (Dieter et al., 2018). Also, agricultural production alone is responsible for 80% of all consumptive water use in the U.S. (USDA ERS, 2019). Given current water shortages across the West and growing concern for future water availability, there is an interest to encourage the adoption of more efficient irrigation practices in agriculture. Drip irrigation systems are particularly efficient in terms of water use, as they deliver water directly to root areas of plants thereby reducing water evaporation and surface runoff compared to other irrigation systems.

However, there is also a question of whether water-saving irrigation practices, such as drip irrigation, are economically viable for producers to adopt, and whether revenues can compensate producers for the additional costs associated with implementation and maintenance. Short- and long-term economic profitability is necessary to motivate the adoption of new, efficient irrigation practices. This report examines the economic profitability of onions produced under drip versus furrow irrigation systems in Northern Utah.. We compare estimated yearly returns of onion production and net present value (NPV) over 15-year period under these two irrigation systems to provide recommendations for producers and policy makers.

Data Sources and Description

In this section, we describe the data used in the analysis of returns and NPV of onion production under drip and furrow irrigation systems. For the estimates of onion production costs, we followed Greenway (2019), which assumed production under drip irrigation system on 150 acres. To obtain production cost under furrow irrigation, we adjusted the irrigation cost, assuming two full-time workers would be needed between May 1st and September 1st at a $15/hour rate, and allocating an additional $10/acre for any repairs, dams, and tubes. Yearly production costs associated with furrow irrigation are lower than costs under drip irrigation (see table 1). However, the actual total production costs under furrow and drip irrigation, including irrigation costs, will vary from one producer to another.

Similar to Greenway (2019), we considered two alternative marketing strategies—either selling the onions in 50 lb. bags or selling them directly off the field. Prices for yellow onions, sold in 50 lb. bags differentiated by size (medium, jumbo, colossal, super colossal), and shipped from Idaho and Malheur County in Oregon, were obtained from USDA AMS between August 2018 and December 2020. Prices for yellow onions, sold off the field, were obtained for the same region from USDA NASS between 2018 and 2020. Yield per acre under both irrigation systems, differentiated by onion size, were obtained for the 2019 and 2020 growing seasons from sites in West Weber and Bear River City, located in Northern Utah. Table 1 reports assumed production costs, which were fixed in the analysis; averages of the observed prices and yields, which were allowed to vary in the analysis based on the historical observations; and calculated average returns based on average yields and prices in the studied period.

Table 1. Production costs ($/acre), yields (50 lb./acre or cwt/acre), prices ($/50 lb. or $/cwt), and average returns ($/acre) for onions grown under drip and furrow irrigation systems

	Bags (50 lb.)					Off the field (cwt)
	Small	Medium	Jumbo	Colossal	Super colossal	
Irrigation cost – drip	$440.82					$440.82
Irrigation cost – furrow	$154.00					$154.00
Total production cost – drip	$11,045.11					$5,700.17
Total production cost – furrow	$10,758.29					$5,413.35
Average yields – drip	21	226	691	663	321	858
Average yields – furrow	36	231	692	840	278	927
Average prices	$6.97[1]	$6.97	$7.08	$8.06	$9.10	$6.69
Average returns[2] – drip	$2,347.71					$39.85
Average returns[2] – furrow	$3,693.71					$788.28

[1] Price for small onions unavailable, assumed to be the same as price for medium onions.

[2] Yearly returns, assuming average yields, average prices, and 10% culling rate for onions sold in 50 lb. bags.

Table 1 shows that, on average, yields under furrow irrigation are higher compared to drip irrigation during the study period. This is rather unusual given that past studies generally found higher yields under drip irrigation compared to furrow (Halvorson et al., 2008; Sharma et al., 2012). In some cases, the yield was found to be more than double of furrow irrigation yields (Enciso et al., 2015). Other factors influence yield besides the irrigation system used (Allen, 2020). Specifically, both irrigation amount and distance from irrigation inlet varied across the study sites and can effect production. In addition, furrow irrigation was combined with some drip irrigation in the studied sites (for more detail, see Allen, 2020), which could have improved the reported furrow yields. As such, we are unable to isolate the potential effect of drip irrigation on higher yields. Although yields under furrow irrigation, were larger than drip irrigation yields on average in this study, there were also occasions when observed yields under drip irrigation were larger. Table 1 also shows that estimated returns are larger under furrow irrigation than drip irrigation, regardless of the way the onions are marketed. This result assumes average yields and prices, but it is important to consider their variability from year to year and examine the uncertainty associated with the returns due to changes in prices and in particular yields, which vary between drip and furrow irrigation.

Variability in Onion Prices and Yields

In this section, we present estimated distributions of the onion prices and yields based on the historical data. Histograms of observed prices and densities of simulated prices for different sizes of onions sold in 50 lb. bags ($/50 lb.), as well as onions sold off the field ($/cwt), are shown in Figure 1. The plots show that lower prices are more likely than higher prices. As expected, the prices tend to be greater for larger onions compared to smaller onions, and prices are lower for onions sold off the field. Also, the prices of onions sold in 50 lb. bags are a lot more variable (e.g., observed prices of medium onions ranged between $4.50-$14.00/bag) than prices of onions sold off the field (observed prices ranged between $6.30-$7.40/cwt).

Figure 1. Observed (histograms) and simulated (densities) onion prices

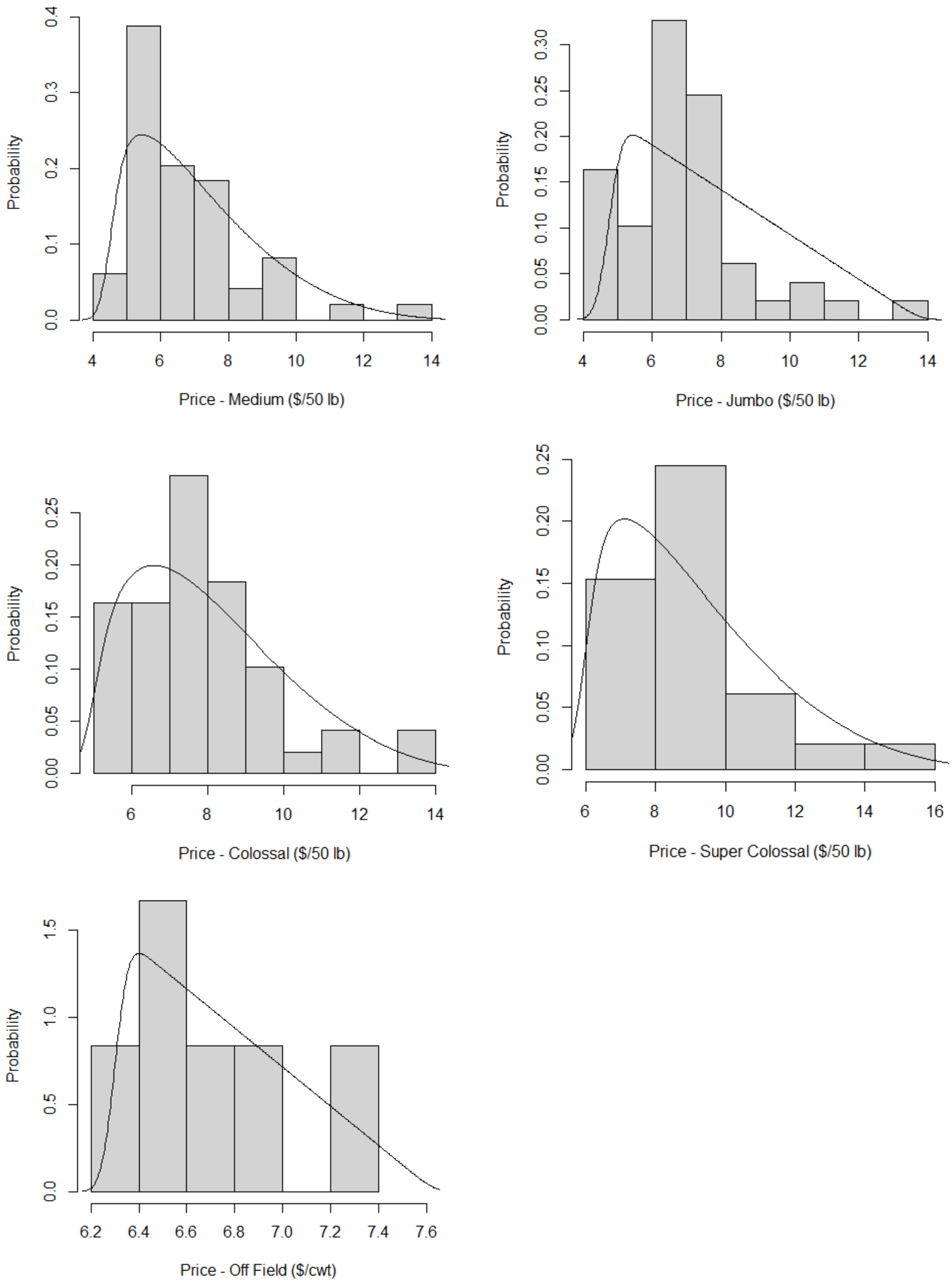
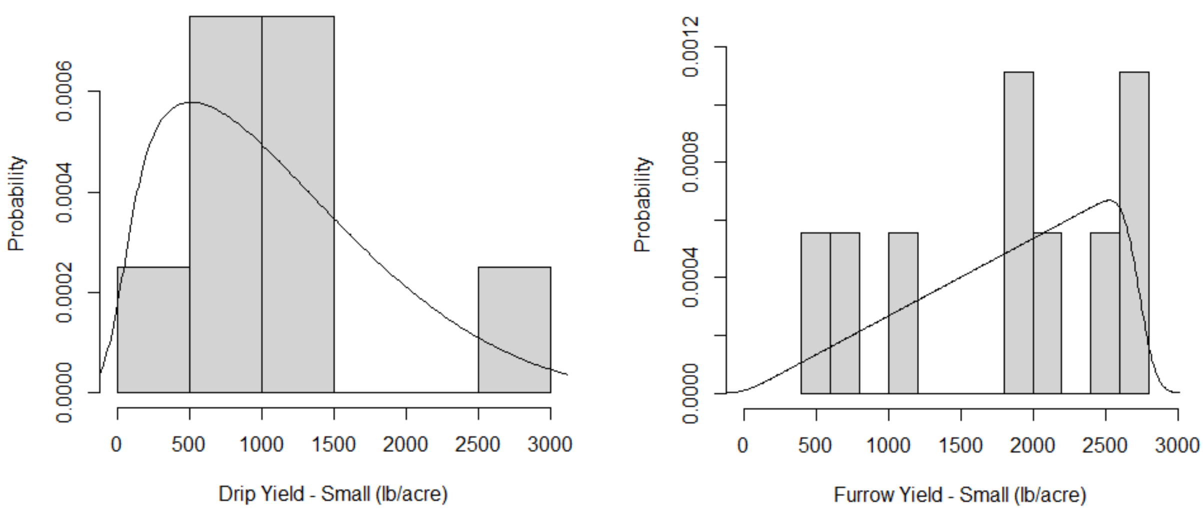
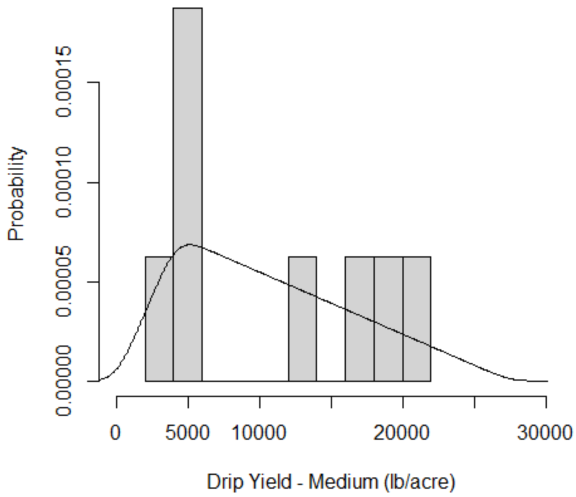


Figure 2 shows histograms of observed yields (lbs./acre) and densities of simulated yields for onions, differentiated by size and grown under drip and furrow irrigation systems. When comparing yields under the two irrigation systems for each onion size, yields tend to be larger under furrow irrigation for small and colossal onions. It is important to note that less than 10 observations were available for each onion size and irrigation system. This has likely impacted the accuracy of the estimated distributions, especially if the available observations were rather unusual. Compared to other studies, greater yields under furrow irrigation than drip irrigation is indeed unusual, as discussed earlier. For now, it is important to keep that in mind when evaluating the returns and NPV.

Figure 2. Observed (histograms) and simulated (densities) onion yields

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0.00010
0.00015
0
5000
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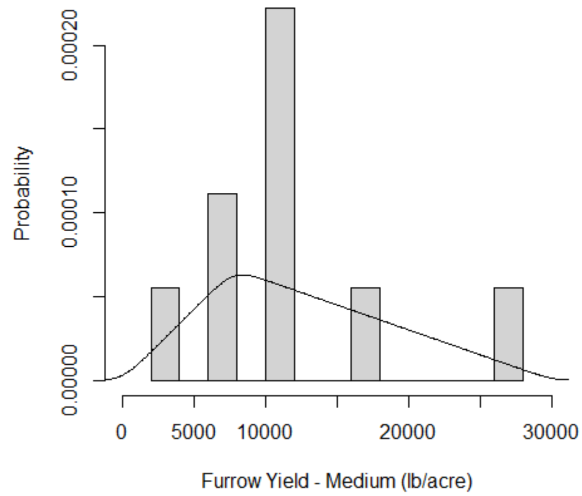
Drip Yield - Medium (lb/acre)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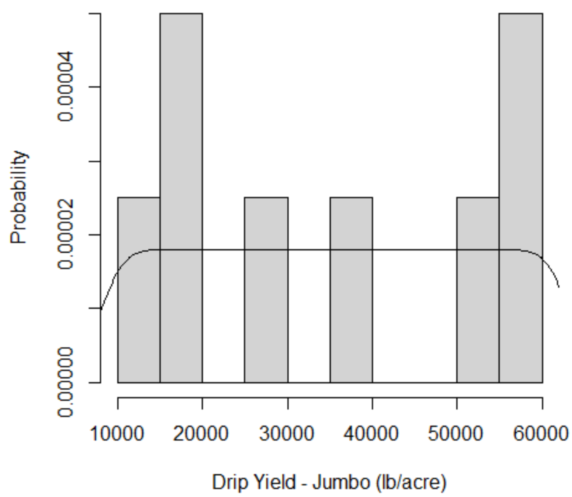
Furrow Yield - Medium (lb/acre)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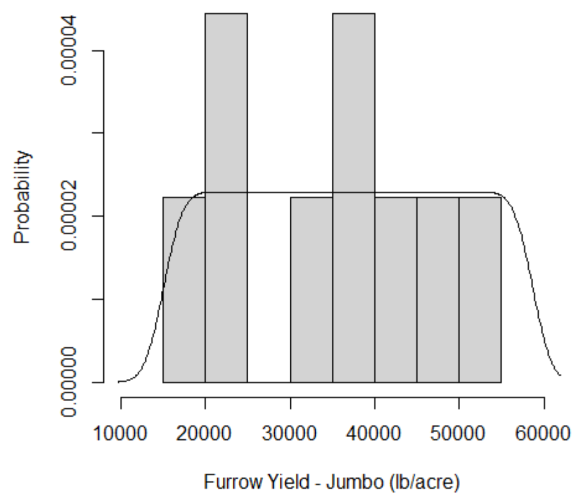
40000
50000
60000
Drip Yield - Jumbo (lb/acre)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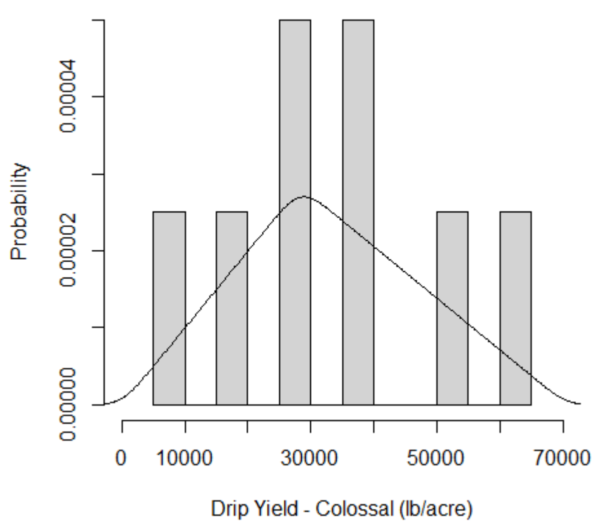
50000
60000
Furrow Yield - Jumbo (lb/acre)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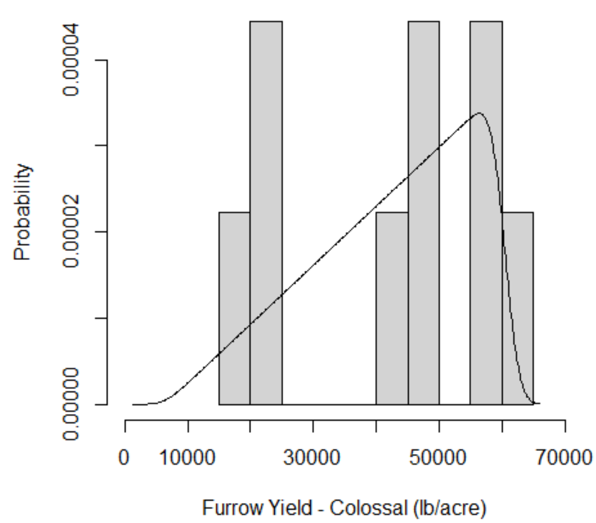
70000
Drip Yield - Colossal (lb/acre)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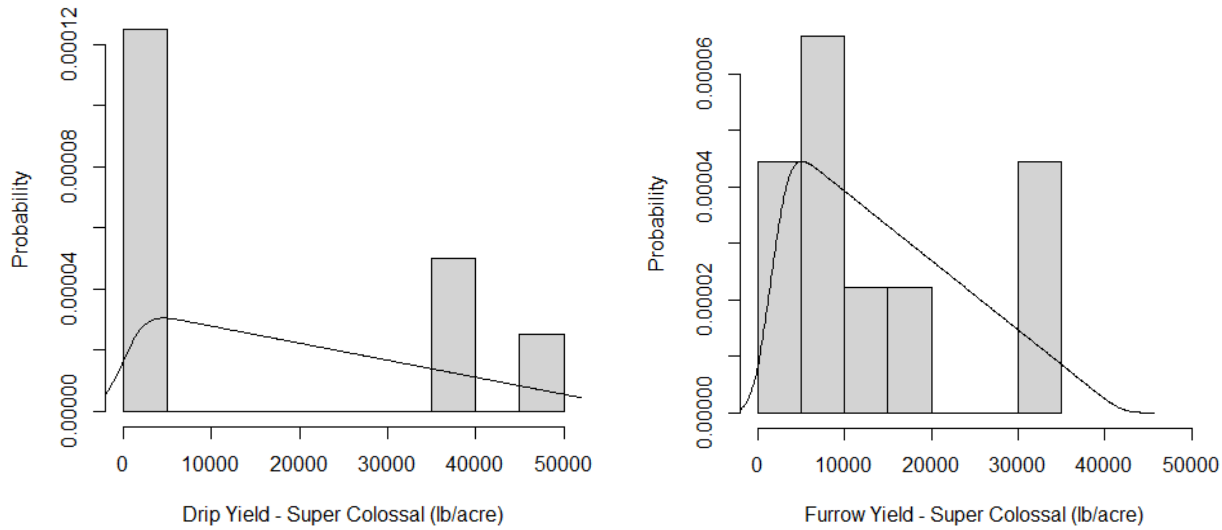
Furrow Yield - Colossal (lb/acre)



Yearly Returns and Net Present Values

In this section, we compare yearly returns and NPV from onions grown under drip and furrow irrigation systems and sold either in 50 lb. bags or off the field. For the NPV estimation, we assumed a 15-year period, a 7% discount rate of future profits, and total production costs per acre assumed a 150 plot. The cost estimates included regular yearly operation and maintenance costs associated with drip and furrow irrigation systems, as applicable. We did not include any potential one-time investments that might be needed regarding these irrigation systems (e.g. well construction) at the beginning of the 15-year period.

Figure 3 shows plots of estimated distributions for yearly returns and NPV over a 15-year period, and Tables 2 and 3 provide more details regarding the distributions. Looking at the distributions of yearly returns, returns tend to be larger for onion production under furrow irrigation compared to drip irrigation and when marketed in 50 lb. bags. Annual returns are also estimated to be greater under furrow irrigation compared to drip irrigation for onions are sold off the field. When selling onions by size in 50 lb. bags, the probability of negative yearly returns is quite high at 22.8% with drip irrigation and 16.3% with furrow irrigation. When selling onions off the field, the probability of negative returns is even higher (35.3% for drip and 20.4% for furrow). In addition, selling onions in bags results in larger returns on average compared to selling onions off the field, making selling onions in bags a better alternative to market onions (while considering 10% culling rate and additional costs associated with packing and sorting onions).

Looking at the NPV over a 15-year period, furrow irrigation is more profitable than drip irrigation. Considering onions sold in bags, the estimated average NPV is a little over $41,000 assuming furrow irrigation and slightly below $30,000 under drip irrigation. The probability of a negative NPV under both irrigation systems is 0%. Thus, even if there are years when the returns are negative, as discussed previously, under this scenario, there are other years with positive returns. However, when selling onions off the field, the estimated probability of a negative NPV is 4.5% with drip irrigation. Another finding is that although onion production under furrow irrigation is more profitable on average, there is also more uncertainty regarding returns and NPV under furrow irrigation because the range of possible outcomes is larger compared to drip irrigation, in particular when selling onions off the field.

Figure 3. Yearly returns and net present value over 15 years ($/acre)

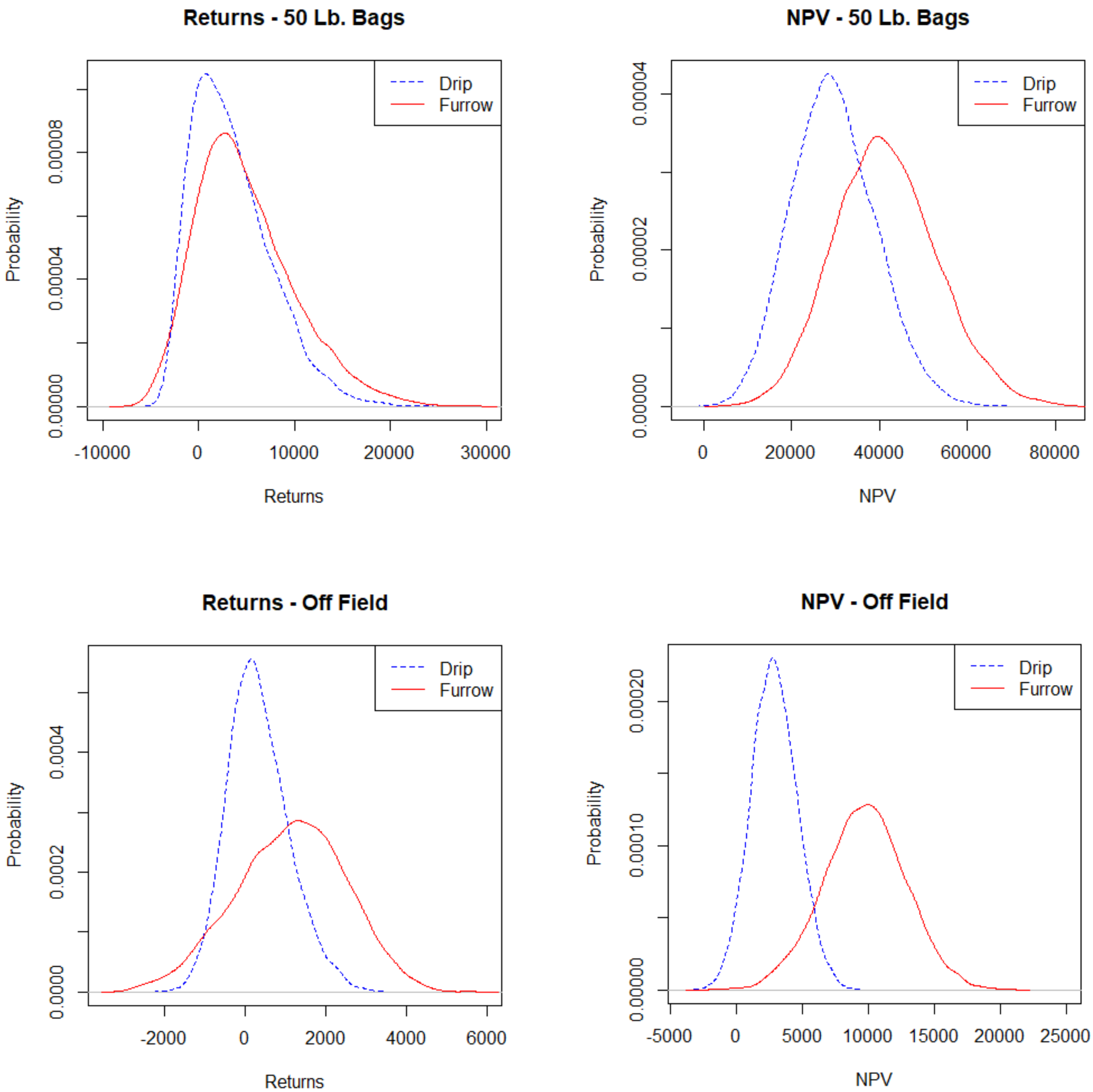


Table 2. Summary of simulated returns and NPV for onions, sold in 50 lb. bags

Statistic	Yearly returns over costs		15-year NPV	
	Drip	Furrow	Drip	Furrow
Average	$3,483.61	$4,868.37	$29,663.99	$41,428.12
Median	$2,789.44	$4,127.67	$29,303.81	$41,031.23

St. dev.	$4,158.62	$5,081.18	$9,504.01	$11,682.75
Minimum	-$4,670.19	-$6,624.70	-$3,202.08	-$1,079.08
Maximum	$25,940.05	$29,491.36	$70,099.18	$88,696.99
Probability of a negative outcome	21.80%	16.30%	0.00%	0.00%

Table 3. Summary of simulated returns and NPV for onions, sold off the field

Statistic	Yearly returns over costs		15-year NPV	
	Drip	Furrow	Drip	Furrow
Average	$340.13	$1,142.43	$2,891.13	$9,719.33
Median	$272.31	$1,205.25	$2,851.51	$9,750.38
St. dev.	$767.28	$1,359.30	$1,748.03	$3,106.59
Minimum	-$2,096.98	-$3,109.24	-$2,861.09	-$1,722.15
Maximum	$3,445.32	$5,166.97	$10,374.16	$19,916.34
Probability of a negative outcome	35.30%	20.40%	4.50%	0.10%

The finding that onion production is more profitable under furrow irrigation than drip irrigation, is based on the available yield observations in the studied area and period. Observed onion yields under furrow irrigation averaged 104,000 lbs./acre (range 60,000-129,000 lbs./acre), while yields under drip irrigation averaged 96,000 lbs./acre (range between 65,000-118,000 lbs./acre). However, comparing that to the 2019-2020 average onion yields at 76,000 lbs./acre across Western U.S. states (with 91,000 lbs./acre in Idaho being the highest), as reported by the USDA, some of the observed yields in this study under both irrigation systems were higher than usual. Yields under furrow irrigation reached even higher levels and more frequently than drip yields, which contributed to the production under drip irrigation being less profitable in comparison, as reported in tables 2 and 3.

However, actual yields reported by producers may be higher or lower than those reported in this study. Thus, we also report estimated yearly returns across a potential range of yields and prices as presented in Tables 4 and 5. These estimates can be used as guidance to estimate returns under a specific yield and price level combination. This allows a comparison of returns under the two irrigation systems across varying yield levels in a single year, but the downside is that there is no probability attached to these estimates. The results show that when the yield is the same under both irrigation systems, production using drip irrigation remains less profitable. This conclusion is is driven by higher yearly costs to maintain drip irrigation systems (assumed in this study). However, if the yields under furrow irrigation are lower than yields under drip (e.g. 90,000 lbs./acre under furrow vs. 105,000 lbs./acre under drip), the production using furrow may be less profitable (e.g. $1,729/acre using furrow vs. $3,472/acre using drip, considering average prices and selling onions in 50 lb. bags). Any final conclusions on the profitability of each system depends on assumed differences in yields. Table 6 reports break-even yields under drip and furrow irrigation systems, showing that higher yields are needed under drip irrigation than under furrow irrigation to break even, but the difference depends on the way the onions are marketed and the price level.

Table 4. Yearly returns using drip irrigation under different yield and price levels

	Yields (lbs./acre)				
	60,000	75,000	90,000	105,000	120,000
40% lower	-$6,068	-$4,824	-$3,579	-$2,335	-$1,091

Prices ($/50 lbs.,	20% lower	-$4,409	-$2,750	-$1,091	$568	$2,227
onions sold in	Average	-$2,750	-$676	$1,398	$3,472	$5,546
bags)[1]	20% higher	-$1,091	$1,398	$3,886	$6,375	$8,864
	40% higher	$568	$3,472	$6,375	$9,278	$12,182
	6.00	-$2,486	-$1,682	-$879	-$75	$728
Prices ($/cwt,	6.40	-$2,272	-$1,414	-$557	$300	$1,157
onions sold off	6.80	-$2,057	-$1,147	-$236	$675	$1,586
the field)	7.20	-$1,843	-$879	$86	$1,050	$2,014
	7.60	-$1,629	-$611	$407	$1,425	$2,443

[1] Prices are based on average prices for 50lb. bags of onions, observed between 08/2018-12/2020 (small/medium = $6.97, jumbo = $7.08, colossal = $8.06, super colossal = $9.10), and decrease/increase from the average by 20% and 40%.

Table 5. Yearly returns using furrow irrigation under different yield and price levels

		Yields (lbs./acre)				
		55,000	75,000	90,000	105,000	125,000
	40% lower	-$6,180	-$4,515	-$3,266	-$2,017	-$352
Prices ($/50 lbs.,	20% lower	-$4,653	-$2,433	-$768	$897	$3,117
onions sold in	Average	-$3,127	-$352	$1,729	$3,810	$6,585
bags)[1]	20% higher	-$1,601	$1,729	$4,227	$6,724	$10,054
	40% higher	-$75	$3,810	$6,724	$9,638	$13,523
	6.00	-$2,467	-$1,395	-$592	$212	$1,283
	6.40	-$2,270	-$1,128	-$270	$587	$1,730

Prices ($/cwt,	6.80	-$2,074	-$860	$51	$962	$2,176
onions sold off	7.20	-$1,878	-$592	$372	$1,337	$2,622
the field)	7.60	-$1,681	-$324	$694	$1,712	$3,069

[1] Prices are based on average prices for 50lb. bags of onions, observed between 08/2018-12/2020 (small/medium = $6.97, jumbo = $7.08, colossal = $8.06, super colossal = $9.10), and decrease/increase from the average by 20% and 40%.

Table 6. Break-even yields (lbs./acre) under drip and furrow irrigation

		Drip irrigation	Furrow irrigation	Difference
	40% lower	133,148	129,229	3,919
Prices ($/50 lbs.,	20% lower	99,861	96,922	2,940
onions sold in	Average	79,889	77,537	2,352
bags)	20% higher	66,574	64,615	1,960
	40% higher	57,064	55,384	1,680
	6.00	106,403	101,049	5,354
Prices ($/cwt,	6.40	99,753	94,734	5,019
onions sold off	6.80	93,885	89,161	4,724
the field)	7.20	88,669	84,208	4,462
	7.60	84,003	79,776	4,227

Conclusions

The aim of this study was to compare and examine the variability of onion yields under furrow and drip irrigation systems, and simulate how the variability in yields affects yearly returns and

NPV over 15 years assuming sales either in 50 lb. bags or off the field. Further, this study aimed to explore if yields under a water-efficient drip irrigation system would be greater than under furrow irrigation systems enough to provide an economic incentive for adoption. We find that yields under the furrow irrigation system in the studied area and period were higher than yields under drip irrigation and combined with slightly lower costs of furrow irrigation, resulted in higher estimated yearly returns and NPV for onions grown under furrow irrigation compared to drip irrigation. This suggests that onion producers do not have an economic incentive to adopt water-efficient irrigation technology.

However, it is important to note that the observed yields under furrow irrigation, were higher than past studies and data reported by USDA (yields under drip irrigation were also higher than usual, although not as high). Thus, the yearly returns and NPV under furrow irrigation might be overestimated in this study. Conversely, the actual costs associated with the onion production under furrow irrigation might be lower than the estimates used in this study. If that would be the case, the estimated yearly returns and NPV under furrow irrigation should be higher, keeping all else the same. We are unable to determine to what extent the potential overestimation of yearly returns and NPV under furrow irrigation, due to unusually higher yields (which resulted in higher revenue), might have been offset with the potential overestimation of the onion production costs under furrow irrigation in this study. However, this study illustrates that onion production under drip irrigation may not be as profitable as production using furrow irrigation, unless yields under drip irrigation are higher, and onion growers in arid states such as Utah may need other incentives to consider the switch to a more water-efficient drip irrigation system.

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Section 3 Remote Sensing for Drip Onion Irrigation Study

By Alfonso Torres-Rua

Date: June 23rd, 2021

The onion study sites (furrow and drip irrigation) are located in West Weber, Utah. According to the USDA WebSoil Survey website[1], the furrow (surface) irrigation site has a silty clay loam texture, at risk of salinization, with a good soil bulk density (1.25 gr/cc) and is potentially at risk of medium to low soil erosion (2TM/yr). For the second site (drip irrigation), the soil has a fine sandy loam soil, with a low risk of salinization, with a good bulk density (1.4 gr/cc), with a high risk of soil erosion (% TM/yr). Examples of the USDA soil characteristics maps are presented in the figure below.

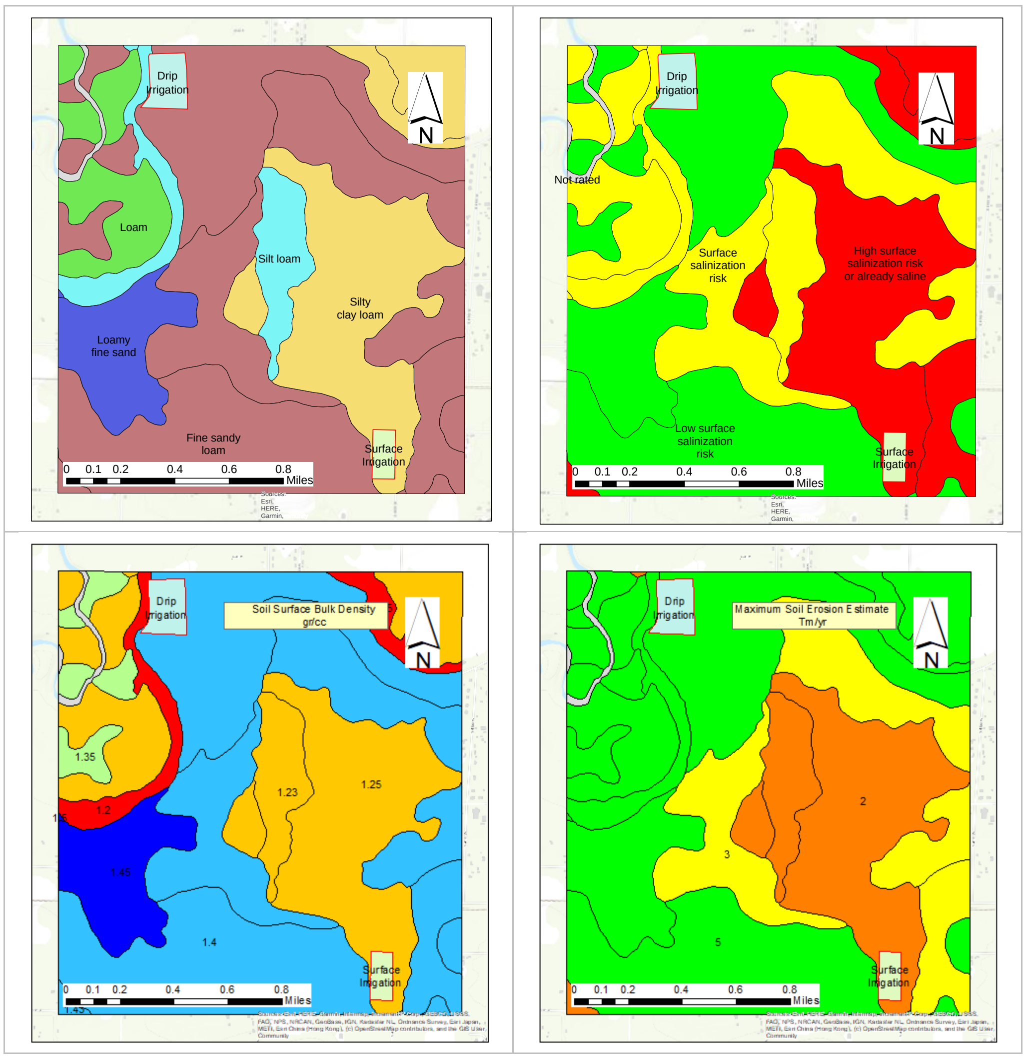
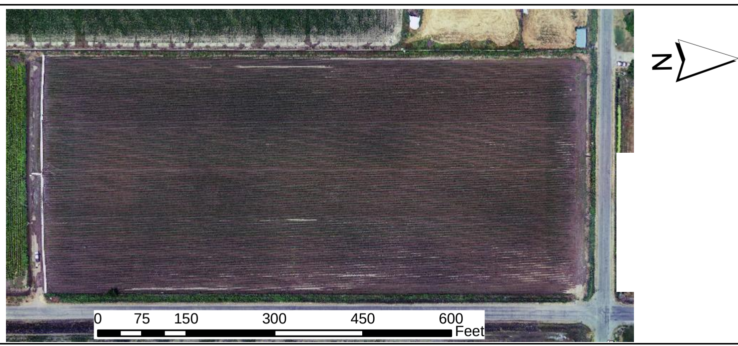


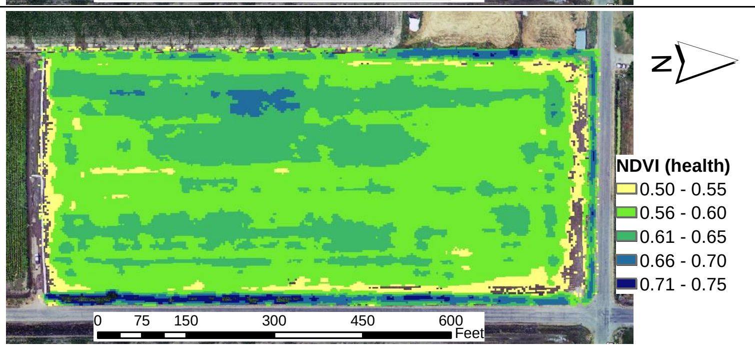
Fig. 1 USDA WebSoil Maps of soil texture, salinity risk, bulk density, and soil erosion risk for two of the study sites in West Weber, Utah

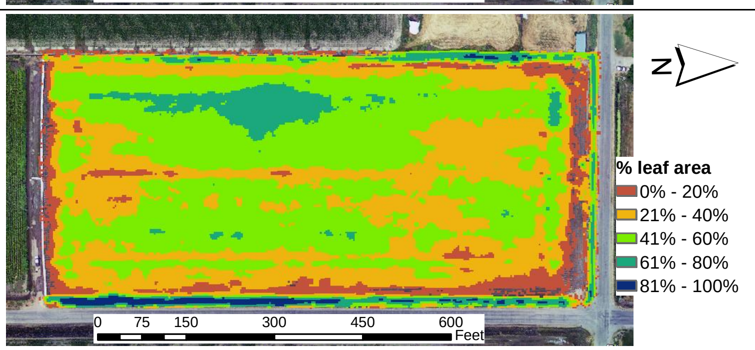
[1] https://websoilsurvey.sc.egov.usda.gov/App/HomePage.htm

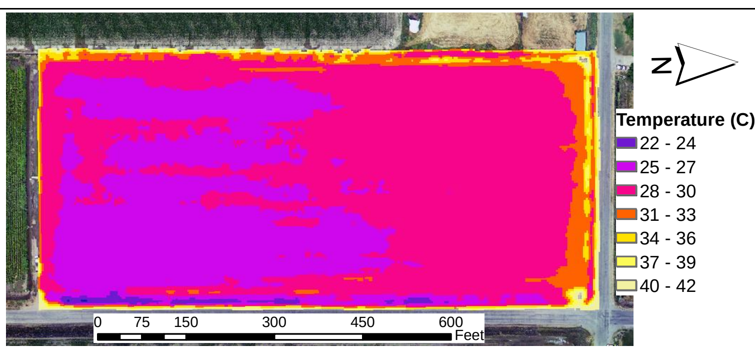
For these two sites, unmanned aerial flights (UAVs) were conducted on July 17th, 2019, to characterize the conditions of the onion vegetation under two different irrigation conditions. Below is the analysis of the UAV information for the two onion sites in 2019.

Surface Irrigation Field:

<table>
<tr>
<td>


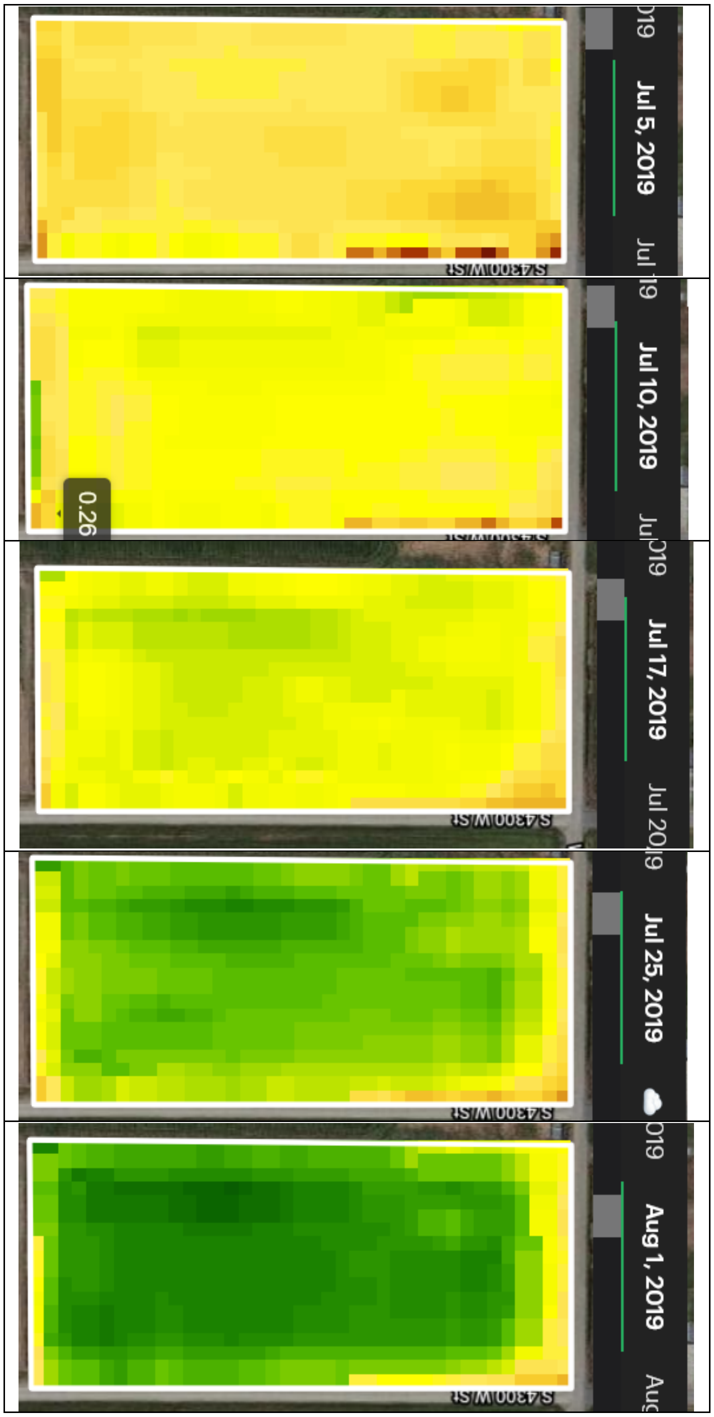
</td>
<td>This location is furrow irrigated. This natural view from the UAV image shows that the soil is dark (silty clay loam), with some more intense green areas along the field. At the moment when UAV was flown, the onion crop had been planted for about ~50 days and under the onion leaves development stage.</td>
</tr>
<tr>
<td>


</td>
<td>The NDVI-vegetation index related to health (higher values are better) of only the onion pixels (after soil pixel removal) shows that onions present a small development at this date, with smaller areas with higher than average NDVI for the field. Overall, the onion health is uniform across the field.</td>
</tr>
<tr>
<td>


</td>
<td>The map of the percentage of onion leaves covering the soil provides a view of the onion growth heterogeneity at this phenological state. Most of the farm has onions leaves covering between 20 to 60% of the soil. This percentage of onions leaves provides an early assessment of onion bulb size. Nevertheless, later application of nutrients will affect this onion leaves development map.</td>
</tr>
<tr>
<td>


</td>
<td>The UAV flight occurred soon after an irrigation event. This is identified by the “low” temperature values across the field. The effect of the surface irrigation can be seen in the colder region on the southern section of the field (irrigation inlet is at the south). Again, the effect of the furrow irrigation shows uniform soil moisture conditions across the field, with a small section at the end of the field, where soil water content is reduced.</td>
</tr>
</table>

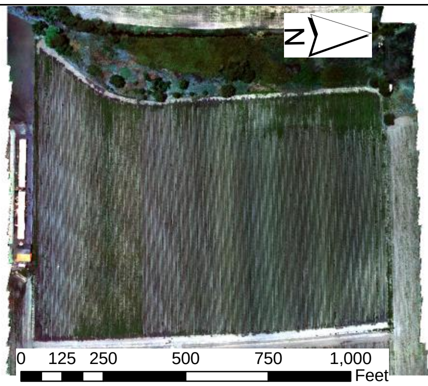
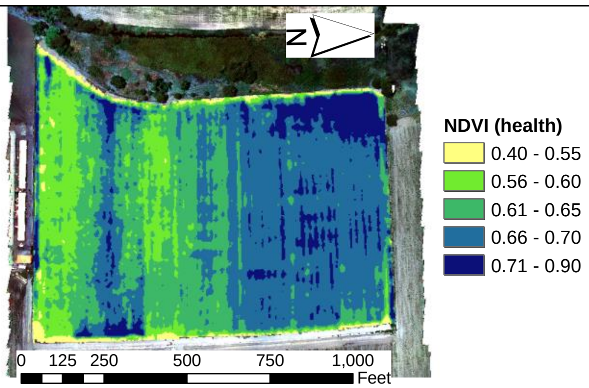
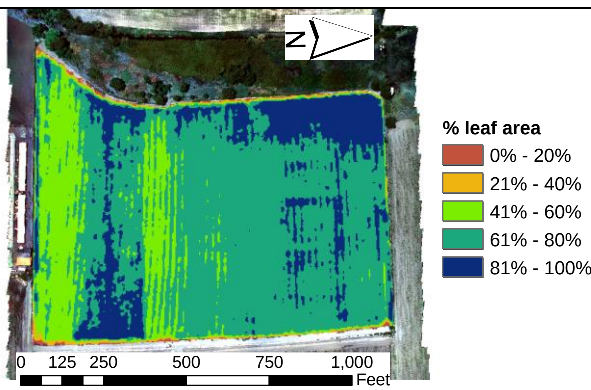
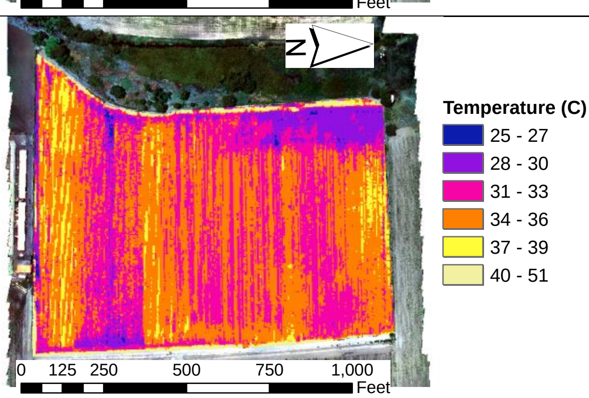
Using the OneSoil NDVI information[2], it is possible to track the onion development from July 5th to August 1st, when onions were approximately harvested. This is shown in the figure below.

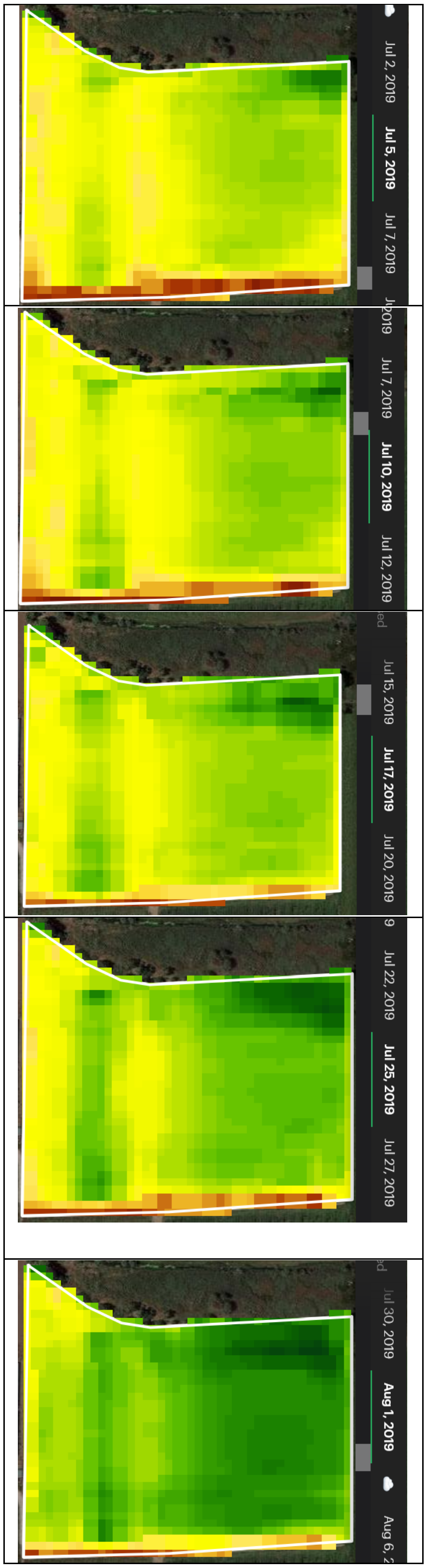


The bright yellow color is an indication of low NDVI (tiny leaves and exposed bare soil). We see, as in the UAV imagery, on the West side of the field, a small area healthier than the rest of the field, a feature that will be present until August. The July 17th NDVI image presents similarities with the UAV information, despite being at a 30-ft/pixel distance. After July 17th, the onion develops further, reaching an overall homogeneity on development across the farm, until before harvest.

[2] https://onesoil.ai/en/

Drip Irrigation field:

	This site has a light color soil, with defined green areas on the north side and near the south. Different from the furrow irrigated site, it seems this field was planted for more than ~50 days by when the UAV flight occurred. The initial assessment is the different patches of greenness (East-West), which can be related to irrigation management (adequately or under/over irrigated)
	The estimation of NDVI values of only the onion leaves provides a different picture for this field compared to the furrow irrigation field. Overall, the onion leaves are much healthier across the northern side of the field and the surface irrigation field. The northwest corner is the one with the highest NDVI crop health, possibly due to soil characteristics in that location. The irrigation management effect is more easily visible, with low NDVI sections at the center and south sections of the field
	In terms of onion leaves development, there is a larger percentage of leaves in this field than in the surface irrigation field on the locations where NDVI is high. Nevertheless, a comparison with the furrow irrigated field cannot be made due to the early planning of this field. Still, irrigation management effects are seen in this field, with similar patterns as in the NDVI map.
	In terms of temperature, this field has pronounced cold and hot temperature areas, which is an indicator of irrigation issues. These East-West sections with hotter temperatures are under irrigated or irrigated less than other locations in the field, thus affecting the onion development, as seen in the NDVI and onion leaves percentage maps. Overall, the temperature of the hotter areas about 10 degrees higher, as an indication of significantly lower moisture conditions in the soil.



The information of NDVI from the OneSoil website also confirms the findings of the UAV information. By July 5th, there was already onion leaf development in the northern and near to the south of the drip-irrigated field, which was not occurring at the furrow irrigated location. The northwest corner of the drip-irrigated field presents a high NDVI value, which indicates that soil characteristics are different there. The July 17th imagery confirms the UAV findings, and by August 1st, most of the field has reached uniform health conditions, but there are East-West areas where NDVI did not increase as other field areas. Overall, it seems that while drip irrigation conditions were more beneficial to onions in terms of health and leaf development in the sections of the field where irrigation was adequate, this not happened uniformly across the field, thus affecting harvest production.

When comparing the UAV NDVI, % leaves maps, and the OneSoil maps, for both irrigation and furrow irrigations, it is evident that drip irrigation requires additional expertise to avoid under irrigation areas in the field. In addition, having a way to often assess field characteristics like NDVI from UAV or OneSoil, similar imagery, or temperature maps will provide the necessary information to identify troublesome areas in drip irrigation (under irrigation and soil characteristics effect).

Activities to continue: Analysis of the soil moisture information of both sites is under progress to determine water use across the field and uniformity. In addition, UAV imagery will be evaluated to estimate evapotranspiration at row scale to determine crop water use uniformity and soil impact on the evapotranspiration rates.

Long-Term Water Optimization Trials: Stacking Conservation Practices
Matt Yost, Earl Creech, Niel Allen, Boyd Kitchen, and Randall Violett

INTRODUCTION

This project seeks to provide agricultural producers and water managers with tools for optimizing agriculture water use. USU is partnering with SUU, the irrigation industry, Water Conservancy Districts, soil and water conservation districts, Utah water agencies, and several other federal and state organizations to evaluate and demonstrate over 25 different water optimization practices. The major objective is to **"*identify which combinations of pivot irrigation and crop management practices result in optimized use of limited water supplies, reduced consumptive use, and the best yield and profit outcomes for producers.*"** The trials include evaluations of pivot irrigation technologies such as MDI, LEPA, and LESA. It is also evaluating how the best available drought-tolerant crop genetics, cover crops, tillage practices, and alternative crops influence water optimization. These side-by-side evaluations are the first of their kind and were established in Logan in 2019, Vernal in 2020, and Cedar City in 2021. This information should be especially useful in guiding water conservation planning at the farm level, which would in turn have large impacts on planning efforts at watershed and basin levels. It will also help irrigators prepare to effectively participate in water demand and banking programs, should they be developed and necessary.

Photo 1. Water optimization trial (20 acres) at the Utah State University Wellsville Farm.

RESULTS TO DATE

Corn. Irrigation technologies, irrigation rates, and drought-tolerant genetics had only minor impacts on yield in 2019 at the Logan site due to an abnormally wet spring. In contrast, most factors influenced silage corn yield in 2020 in Logan, and at the new established site in Vernal. The interaction of irrigation technology and irrigation rate was significant at both sites, with results suggesting that the higher efficiency sprinklers (LEPA, and LESA) can result in higher yields when irrigation rates are reduced. Treatment type was heavily influenced by the irrigation technology as well at both sites. The addition of the soil wetting agent did not improve yield at reduced rates and thus would not be warranted. At reduced irrigation rates, drought-tolerant genetics rarely improved yield. No-till only sometimes decreased yield and reductions were more pronounced when water stress was greater. Targeted 50% irrigation rate reductions to critical crop growth stages was often worse and never better than a straight 50% reduction in rate all season.

Alfalfa
Two cuttings of alfalfa were harvested in 2020 in Logan. A total of 13.5 inches of irrigation was applied for both cuttings for the full irrigation rate. The irrigation reductions were achieved by changing nozzles sizes on the linear where alfalfa received 25 or 50% less water each irrigation. When irrigation was reduced by 25%, alfalfa yield was reduced by an average of about 0.75 tons/acre (20%) total for the two cuts. A 50% reduction in irrigation produced 1.2 tons/acre less yield (30% reduction). Results were mixed for the 50% targeted irrigation. It was much worse than the straight 50% reduction for the first cut, but much better in the second cut.

Small Grains Forage. Small grain forage yield in 2020 ranged from 1.5 to over 3.5 tons per acre. The LESA system at full irrigation produced the greatest yield, while the MDI produced the least. All systems except LESA were able to maintain yield with 25% less water. MESA was the only system where the 50% reduction also maintained yield compared to full irrigation. This indicates that small grain forage has a great ability to withstand water stress, and that traditional MESA systems may have some of the greatest potential. Small grain forage quality was only impacted by irrigation rates. Forage quality increased as water stress increased. This is likely because less growth in water-stressed areas can reduce plant stem, which can improve forage quality. Quality and yield data will be combined to examine the economics of these treatments.

Alternative Crops. Teff was the alternative crop in Vernal. At full irrigation, all irrigation systems besides MDI (poor yield in all treatments) performed equally well. None of the three advanced irrigation systems could maintain yield with 25% less irrigation. However, for MESA and LESA, the 50% reduction yielded the same as the 25% reduction in irrigation rate. Teff forage quality was also measured in LESA irrigation systems only.

OTHER RESOURCES

MESA LESA LEPA MDI

Pivot Irrigation System Comparisons

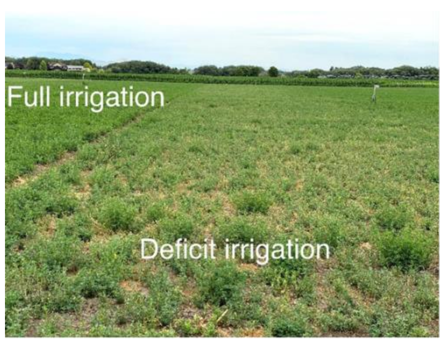


Photo 2. Full and deficit irrigation alfalfa research plots at the USU Wellsville Farm.

Deficit Irrigation for Forages

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